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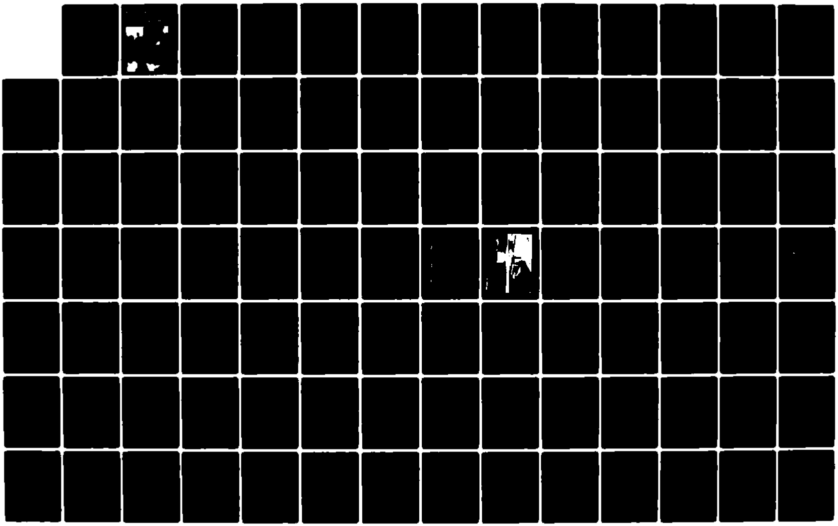

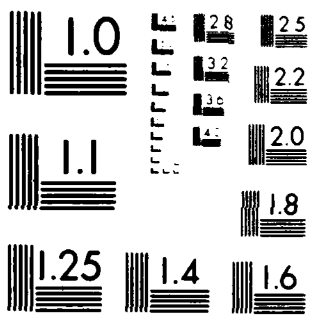
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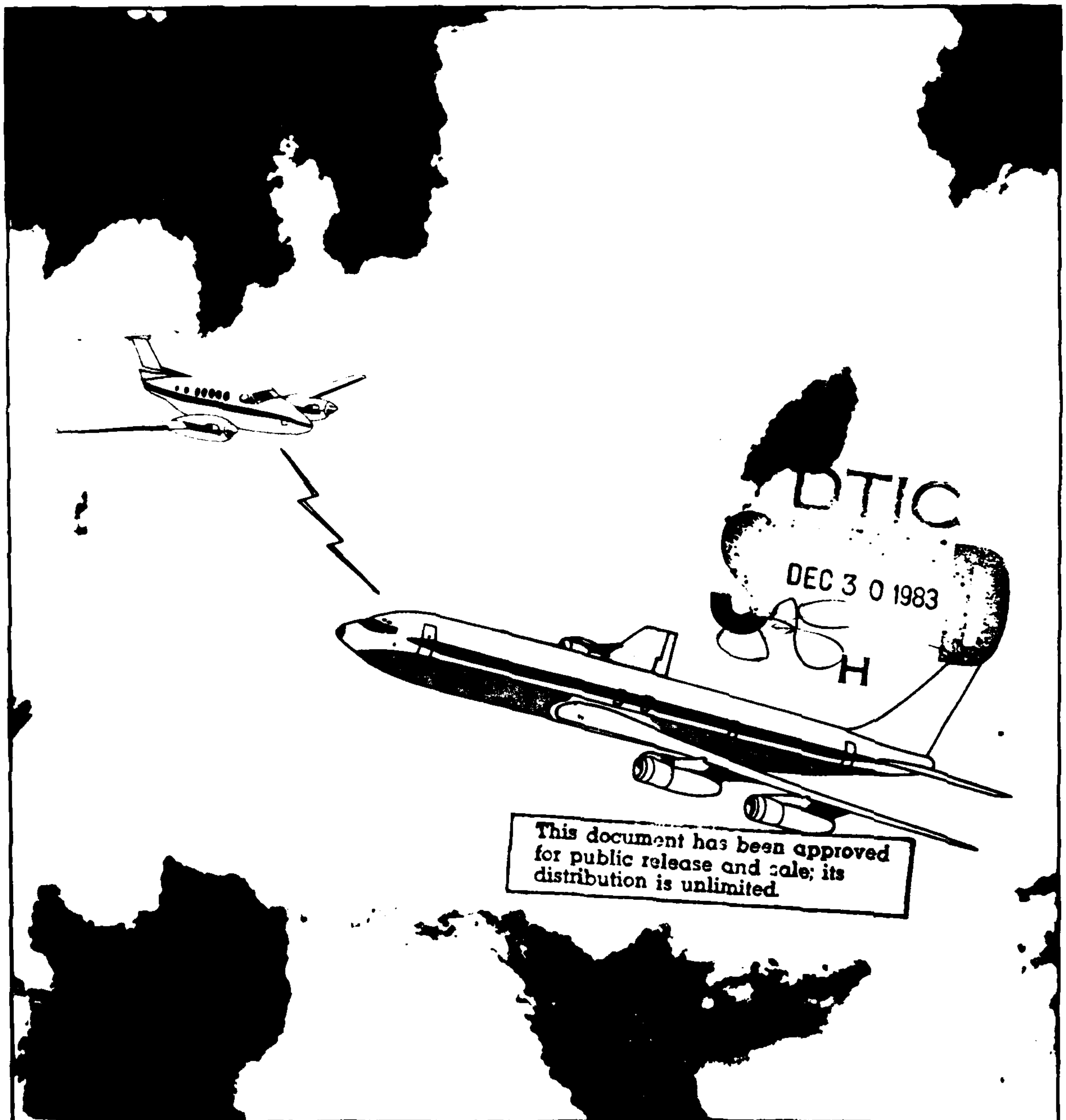
TCAS
Traffic Alert and Collision Avoidance System
Symposium

October 12—13, 1982



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15. Supplementary Notes

16. Abstract

The Federal Aviation Administration held its third symposium on Traffic ~~Threat~~ Alert and Collision Avoidance System (TCAS) in Washington, D.C., October 12-13, 1982, which was attended by representatives of organizations and airlines. This report contains twelve technical presentations discribing the progress of the TCAS program.

The TCAS will provide a range of capabilities and costs which will meet the requirements of all airspace users. The least complex part of the system is designed for private pilots and would cost about $2,500. The fully capable, or airline, version would cost between $45,000 and $50,000.

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AGENDA

FOR

THIRD TCAS SYMPOSIUM

FEDERAL AVIATION ADMINISTRATION

800 INDEPENDENCE AVENUE, SW.

WASHINGTON, D.C.

OCTOBER 12-13, 1982

TUESDAY, OCTOBER 12, 1982

TIME	TITLE	AUTHOR
10:30 a.m.	Welcome and Review of Agenda	A. Albrecht
10:40 a.m.	Status of TCAS	M. Pozesky
10:50 a.m.	Overview of Operational Evaluation Activities	K. Hunt
11:05 a.m.	TCAS Program	C. Miller

LUNCH BREAK

(11:30 - 1:00 p.m.)

1:00 p.m.	Status of Mode S Implementation	D. Hodgkins
1:30 p.m.	TCAS II Operational Doctrine	C. Miller
2:00 p.m.	Comparison of TCAS I Passive and Active Transponder Detection	V. Orlando
2:30 p.m.	Aircraft Traffic Density in the Los Angeles Basin as Related to TCAS Requirements	N. Spencer

COFFEE

(3:00 - 3:30 p.m.)

3:30 p.m.	Surveillance Techniques for Minimum TCAS II	J. Welch
4:00 p.m.	Validation of Surveillance Techniques for Minimum TCAS II	W. Harman
4:30 p.m.	Enhanced TCAS II	E. Reed

CASH BAR

(Holiday Inn, 5:00 - 7:30 p.m.)

WEDNESDAY, OCTOBER 13, 1982

TIME	TITLE	AUTHOR
8:30 a.m.	Minimum TCAS II Threat Detection and Resolution Logic Status	A. Zeitlin
9:00 a.m.	Minimum TCAS II Threat Detection and Resolution Logic Testing	B. Billmann
9:30 a.m.	Minimum TCAS II	D. Stoddart

COFFEE

(10:00 - 10:30 a.m.)

10:30 a.m.	Evaluation of TCAS II in an Air Carrier Environment	W. Hyland
11:00 a.m.	Operation Evaluation of TCAS II Traffic Advisories	J. Andrews

LUNCH BREAK

(11:30 - 1:00 p.m.)

1:00 p.m. Panel Discussion

Clyde Miller	Jerry Welch	Don Stoddart
Bud Hyland	Andy Zeitlin	Emory Reed
	Dave Harrington	Tom Berry

WELCOME AND REVIEW OF AGENDA

(AL ALBRECHT)

GOOD MORNING!

IT IS MY PLEASURE TO WELCOME EACH OF YOU TO THE THIRD IN OUR SERIES OF TECHNICAL CONFERENCES ON THE TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM, OR TCAS. THESE MEETINGS CONTINUE OUR TRADITION OF SEEKING THE PARTICIPATION OF THE FULL SPECTRUM OF THE AVIATION COMMUNITY IN DEVELOPING A VIABLE INDEPENDENT AIRBORNE SEPARATION ASSURANCE CAPABILITY TO BACKUP THE CONVENTIONAL AIR TRAFFIC CONTROL SYSTEM. THE OBJECTIVE OF THIS CONFERENCE IS TO DISTRIBUTE TECHNICAL AND OPERATIONAL PERFORMANCE INFORMATION THAT HAS BEEN DEVELOPED SINCE OUR LAST MEETING.

THE PRINCIPAL FOCUS OF THE TCAS PROGRAM IS ON THE ACTIVITIES OF THE RADIO TECHNICAL COMMISSION FOR AERONAUTICS SPECIAL COMMITEE 147. THIS COMMITTEE IS DEVELOPING MINIMUM OPERATIONAL PERFORMANCE STANDARDS (or MOPS) FOR MINIMUM TCAS II AS WELL AS GUIDELINES FOR TCAS I. WE ARE EXTREMELY PLEASED THAT THIS COMMITTEE HAS BEEN ABLE TO COMPLETE A COMPREHENSIVE DRAFT OF THE MOPS. THE INFORMATION PRESENTED OVER THE NEXT TWO DAYS SHOULD AID SC-147 IN COMPLETING THEIR WORK IN THE NEAR TERM.

WHILE MUCH OF THIS CONFERENCE IS DIRECTED TOWARD THE MOPS FOR MINIMUM TCAS II, THERE HAVE BEEN PROMISING DEVELOPMENTS IN THE TCAS I AND ENHANCED TCAS II AREAS AS WELL. WE ARE ANXIOUS THAT YOU, THE COMMUNITY THAT WILL IMPLEMENT TCAS, HAVE EARLY ACCESS TO THESE RESULTS.

OUR LAST MEETING, IN JANUARY, WAS HEAVILY CONCENTRATED ON ENGINEERING DATA. WHILE ENGINEERING TOPICS PREDOMINATE AT THIS CONFERENCE AS WELL, YOU WILL RECOGNIZE THAT THE EMPHASIS IS MOVING FROM TECHNICAL RESULTS TOWARD OPERATIONAL DOCTRINE AND CONCEPTS.

WE HAVE A FULL AGENDA. AFTER AN OVERVIEW OF THE STATUS OF TCAS PROVIDED BY MARTY POZESKY, KEN HUNT, DIRECTOR OF THE OFFICE OF FLIGHT OPERATIONS, WILL DESCRIBE WHAT WE HAVE LEARNED FROM OPERATIONAL EVALUATION ACTIVITIES, AND WHAT REMAINS TO BE DONE IN THIS AREA. THIS WILL BE FOLLOWED BY AN OVERVIEW OF TCAS PROGRAM ACTIVITIES WHICH DISCUSSES ACTIVITIES RECENTLY COMPLETED AND THOSE THAT ARE PLANNED FOR THE FUTURE. TCAS CONTINUES TO BE ONE OF THE HIGHEST PRIORITY PROGRAMS IN THE AGENCY. YOU WILL SEE THAT THE SCOPE OF OUR PROGRAM CONTINUES TO GROW.

THE AGENCY'S PROGRAM TO IMPLEMENT MODE S GROUND STATIONS AND ASSOCIATED DATA LINK SERVICES IS THE NEXT ITEM ON OUR AGENDA. WE RECOGNIZE THAT PLANS FOR MODE S AIR-GROUND DATA LINK ARE A PRINCIPAL FACTOR IN COMMUNITY ACCEPTANCE OF THE TCAS I CONCEPT. WE ALSO KNOW THAT THE AIR CARRIER COMMUNITY IS INTERESTED IN THESE PLANS, BOTH FROM THE STANDPOINT OF SERVICES THAT WILL BE PROVIDED AND FROM THE STANDPOINT OF IMPLICATIONS FOR AVIONICS ARCHITECTURES FOR DATA LINK.

THE TALK ON OPERATIONAL DOCTRINE FOR MINIMUM TCAS II IS INTENDED TO SET THE STAGE FOR MUCH OF WHAT FOLLOWS. MINIMUM TCAS II IS NOW WELL DEFINED, AND WE ARE VERY CLOSE TO A FULL UNDERSTANDING OF ITS CAPABILITIES AND ITS LIMITATIONS. THE OPERATIONAL USE OF TCAS II MUST BE CONSISTENT WITH THE TECHNICAL CHARACTERISTICS OF THE SYSTEM AND THE ENVIRONMENT IN WHICH IT OPERATES. WE HAVE DEVELOPED SUCH AN OPERATIONAL DOCTRINE AS THE BASIS FOR OUR NEAR TERM OPERATIONAL EVALUATION ACTIVITIES WITH THE EXPECTATION THAT WE WILL EMBELLISH AND EXTENT THIS CONCEPT AS WE GAIN OPERATIONAL EXPERIENCE.

THE TCAS I PRESENTATION WILL REMIND YOU THAT OUR EARLY IDEAS FOR THE TRANSPONDER DETECTOR FUNCTION WERE FOCUSED ON PASSIVE LISTENING TECHNIQUES. THESE TECHNIQUES HAD THE ADVANTAGE THAT THEY INTRODUCED NO NEW INTERFERENCE IN THE ENVIRONMENT. UNFORTUNATELY, WE WERE UNABLE TO INVENT PASSIVE TECHNIQUES THAT PROMISED A TRULY HIGH QUALITY TRAFFIC ALERTING CAPABILITY. WE SUBSEQUENTLY RECOGNIZED THAT LOW POWER INTERROGATIONS FROM TCAS I AIRCRAFT COULD SUPPORT A QUALITY TRAFFIC ADVISORY SERVICE WITHOUT SIGNIFICANTLY DEGRADING THE ENVIRONMENT. OUR ASSESSMENT THAT THIS ACTIVE MODE TCAS I MAY BE NO MORE EXPENSIVE THAN A PASSIVE MODE TCAS I LEADS US TO BELIEVE THAT WE HAVE IN HAND A PROMISING NEW CAPABILITY FOR THE GENERAL AVIATION COMMUNITY.

WE HAVE OWED YOU A VALIDATION OF THE TRAFFIC DENSITY FORECASTS UPON WHICH TCAS II SURVEILLANCE REQUIREMENTS ARE BASED. WHEN WE FIRST DISCUSSED TCAS WITH YOU, WE SAID THAT WE ANTICIPATED DENSITIES AS HIGH AS 0.3 AIRCRAFT PER SQUARE MILE THROUGH 1990 WITH THE PROSPECT THAT DENSITIES COULD BECOME AS HIGH AS 0.4 AIRCRAFT PER SQUARE NAUTICAL MILE BY THE YEAR 2000. THESE DENSITIES WERE ESTIMATED AS THE PEAK DENSITIES THAT WOULD EXIST OVER SMALL REGIONS OF TERMINAL AIRSPACE WITHIN WHICH TCAS II MAY BE RESOLVING ENCOUNTERS WITH 500 KNOT INTRUDERS (THAT IS, PEAK DENSITIES OVER REGIONS WITH A RADIUS OF 5 NMI). WE HAVE COLLECTED NEW DATA AND MADE NEW PROJECTIONS. OUR TALK ON THIS SUBJECT WILL TELL YOU THAT OUR PROJECTIONS HAVE NOT CHANGED.

THE NEXT THREE TALKS ON THE AGENDA DISCUSS THE STATUS OF THE TCAS II SURVEILLANCE DESIGNS. WE CONTINUE TO EVALUATE THE MINIMUM TCAS II HIGH DENSITY DESIGN DESCRIBED IN THE MOPS. AS WE SEE MORE DATA, WE ARE INCREASINGLY CONFIDENT. MOREOVER, WE HAVE COMPLETED A COMPREHENSIVE ANALYSIS OF THE FEASIBILITY OF HORIZONTAL RESOLUTION GIVEN THE CHARACTERISTICS OF THE ENHANCED TCAS II SURVEILLANCE DESIGN. THESE RESULTS ARE ALSO ENCOURAGING.

TOMORROW MORNING BEGINS WTH AN OVERVIEW OF THE MINIMUM TCAS II THREAT DETECTION AND RESOLUTION LOGIC. THESE TALKS WILL BE FOLLOWED BY A DESCRIPTION OF THE MINIMUM TCAS II UNIT THAT WE EXPECT TO USE AS THE BASIS FOR OUR FIRST FULLY OPERATIONAL EVALUATION IN THE AIR CARRIER ENVIRONMENT. THIS UNIT IMPLEMENTS THE TRAFFIC ADVISORY FUNCTION OF TCAS II.

THE FINAL TWO TALKS ON OUR AGENDA DESCRIBE THE DISPLAYS AND ALERTING FEATURES ENVISIONED FOR MINIMUM TCAS II IN THE AIR CARRIER COCKPIT AS WELL AS THE WAYS IN WHICH FLIGHT CREWS UTILIZE TRAFFIC ADVISORY INFORMATION.

WE CONCLUDE TOMORROW AFTERNOON WITH A PANEL OF SPEAKERS THAT WILL BE ANXIOUS TO DISCUSS ANY RELEVANT TOPIC WITH YOU. WE REGRET THAT TIME PERMITS ONLY A FEW MINUTES OF DISCUSSION FOLLOWING EACH TALK. THE COFFEES DOWNSTAIRS AND THE CASH BAR AT THE HOLIDAY INN THIS EVENING WILL GIVE US AN OPPORTUNITY FOR ADDITIONAL DISCUSSIONS.

BEFORE I STEP DOWN, I WANT TO THANK YOU AGAIN FOR YOUR PARTICIPATION IN THIS CONFERENCE. TCAS IS DOING WELL. THIS SUCCESS HAS BEEN POSSIBLE BECAUSE THE COMMUNITY HAS SUPPORTED THE PROGRAM IN PURSUIT OF OUR COMMON GOAL.

IT IS MY PLEASURE NOW TO INTRODUCE MARTY POZESKY, DIRECTOR OF THE PROGRAM ENGINEERING AND MAINTENANCE SERVICE. MARTY WILL PROVIDE AN OVERVIEW OF THE STATUS OF TCAS.

STATUS OF TCAS

(MARTY POZESKY)

THANK YOU, AL.

GOOD MORNING LADIES AND GENTLEMEN. WELCOME TO OUR CONFERENCE. AL HAS MADE THE POINT THAT TCAS CAN SUCCEED ONLY TO THE EXTENT THAT YOU, THE COMMUNITY, SUPPORT IT. YOUR PARTICIPATION IS ESSENTIAL. THANK YOU FOR COMING.

OUR DEVELOPMENT AND EVALUATION ACTIVITIES SINCE THE LAST CONFERENCE HAVE LEAD US TO SOME CONCLUSIONS AND HAVE ENCOURAGED US TO UNDERTAKE SOME NEW INITIATIVES. MY PURPOSE IS TO DESCRIBE THESE ITEMS TO YOU. I ALSO WANT TO MAKE A FEW REMARKS ABOUT THE ARINC CHARACTERISTIC FOR MINIMUM TCAS II.

AS A RESULT OF OUR IN-SERVICE EVALUATION ON PIEDMONT AIRLINES, IT IS NOW EASY FOR US TO ENVISION THAT A RESOLUTION ADVISORY MAY BE DISPLAYED IN AN AIR CARRIER COCKPIT WHEN THE CREW HAS OTHER INFORMATION WHICH TELLS THEM THAT COMPLIANCE WITH THE ADVISORY IS UNNCESSARY. FOR EXAMPLE, THE CREW MAY HAVE VISUALLY ACQUIRED THE INTRUDING AIRCRAFT AND MAY BE MAINTAINING VISUAL SEPARATION WITH CONCURRENCE FROM ATC. UNDER SUCH CONDITIONS OF INTENTIONAL PROXIMITY, TCAS MAY GENERATE RESOLUTION ADVISORIES THAT CREWS WILL NOT FOLLOW.

OUR EXPERIENCE WITH ENCOUNTERS OF THIS TYPE HAS LEAD US TO TWO CONCLUSONS. OUR FIRST CONCLUSION IS THAT WE WILL DROP THE "ABOVE/BELOW" INDICATION IN THE CROSS-LINK TO TCAS I. WHEN TCAS II IS IN CONFLICT WITH TCAS I, TCAS II CROSS-LINKS A TRAFFIC ADVISORY TO TCAS I THAT REFLECTS THE POSITION OF TCAS II AS VIEWED FROM TCAS I. UNTIL RECENTLY, THE CROSS-LINK MESSAGE ALSO REFLECTED THE RESOLUTION ADVISORY DISPLAYED IN THE TCAS II COCKPIT. FOR EXAMPLE, IF TCAS II SELECTED "CLIMB", IT WOULD NOTIFY TCAS I THAT IT INTENDED TO PASS ABOVE. IF THE PILOT OF TCAS II VISUALLY ACQUIRED TCAS I AND USED THIS INFORMATION TO PASS BELOW, THE CROSS-LINK MESSAGE COULD EASILY MISLEAD THE PILOT OF THE TCAS I AIRCRAFT. THEREFORE, TCAS II WILL CONTINUE TO ALERT THE TCAS I AIRCRAFT WITH TRAFFIC ADVISORY INFORMATION, BUT THE "ABOVE/BELOW" MANEUVER INTENTION INDICATION WILL BE DROPPED.

OUR SECOND CONCLUSION IS THAT THE TRAFFIC ADVISORY FEATURE OF TCAS II IS ENORMOUSLY IMPORTANT. IT IS THE MEANS BY WHICH THE PILOT KNOWS THAT HIS DISCUSSION WITH ATC AND THE TCAS RESOLUTION ADVISORY ARE BOTH CONCERNED WITH THE SAME TRAFFIC, AND THE MEANS BY WHICH THE PILOT KNOWS THAT THE DISPLAYED RESOLUTION ADVISORY PERTAINS TO THE AIRCRAFT ON WHICH HE IS MAINTAINING VISUAL SEPARATION. WE WILL HAVE MORE TO SAY ON THIS TOPIC EARLY THIS AFTERNOON. THE POINT IS THAT THE TRAFFIC ADVISORY PROVIDES THE LINK BETWEEN THE TCAS RESOLUTION ADVISORY AND CONVENTIONAL SEPARATION ASSURANCE TECHNIQUES BASED ON ATC AND SEE-AND-AVOID. IT IS DIFFICULT TO PERCEIVE THE EFFECTIVENESS OF THE RESOULTION ADVISORY WITHOUT THIS LINK.

MINIMUM TCAS II IS CONVERGING QUICKLY. THE MOPS CAN BE FINISHED IN THE NEAR FUTURE, AND WE EXPECT TO HAVE FULLY OPERATIONAL EVALUATIONS UNDERWAY IN FAA AND PIEDMONT AIRCRAFT BEGINNING IN APRIL OF NEXT YEAR. WE SEEM TO BE CLOSE TO AN OPERATIONAL, INDEPENDENT AIRBORNE SEPARATION ASSURANCE CAPABILITY. ALL OF US ARE ANXIOUS TO ENSURE THAT THE WIDESPREAD IMPLEMENTATION OF MINIMUM TCAS II IS BASED ON A SOUND BACKGROUND OF SAFETY ANALYSIS AND OPERATIONAL EXPERIENCE. THE DEVELOPMENT PROGRAM HAS PROVIDED MUCH OF THIS FOUNDATION, AND THE RTCA ACTIVITIES TO DEVELOP THE MOPS HAVE CONTRIBUTED SUBSTANTIALLY. WE PROPOSE TO AUGMENT THIS BACKGROUND WITH TWO ADDITIONAL ACTIVITIES.

FIRST, WE HAVE LAUNCHED A COMPREHENSIVE SYSTEM SAFETY STUDY OF TCAS II. THIS STUDY WILL DEAL WITH THE EFFECTS OF INTRUDER MANEUVERS, SURVEILLANCE ERRORS TO INCLUDE ALTIMETRY ERRORS, AND UNDETECTED EQUIPMENT FAILURES, BOTH IN THE TCAS UNIT AND IN THE AUTOMATIC ALTITUDE REPORTING EQUIPMENT IN INTRUDING AIRCRAFT. OUR OBJECTIVE IS TO ENSURE THAT THE OPERATIONAL PROCEDURES THAT WE APPLY TO TCAS ARE CONSISTENT WITH TCAS TECHNICAL CHARACTERISTICS AND THE CHARACTERISTICS OF THE ENVIRONMENT IN WHICH TCAS WILL OPERATE. THIS STUDY WILL BE ACCOMPLISHED IN THE NEAR TERM USING EXISTING DATA BASES. WE VIEW COMMUNITY PARTICIPATION IN THIS STUDY AS ESSENTIAL.

THE SECOND ACTIVITY STEMS FROM THE REALIZATION THAT OPERATIONAL EXPERIENCE WITH TCAS IS HARD TO ACCUMULATE. IN 928 HOURS OF OPERATION IN PIEDMONT, WE EXPERIENCED ONLY 25 RESOLUTION ADVISORIES AGAINST AIRBORNE INTRUDERS. TRAFFIC ADVISORIES APPEARED ONLY ONCE IN EVERY 5 HOURS OR SO. SOME OBSERVERS RODE IN THE JUMP SEAT AND WATCHED THE DISPLAYS ALL DAY WITHOUT SEEING A THING. IF WE EXPECT TO ACCUMULATE A QUANTITY OF OPERATIONAL EXPERIENCE IN THE AIR CARRIER FLEET, WE NEED TO HAVE MORE UNITS FLYING THAN WE HAD BEEN PLANNING. WE HAVE DISCUSSED THIS MATTER WITH THE ADMINISTRATOR AND HE HAS DIRECTED US TO UNDERTAKE A LIMITED OPERATIONAL DEPLOYMENT OF MINIMUM TCAS II. AS NOW ENVISIONED, THE PROGRAM WILL PROVIDE A TOTAL OF FROM 10 TO 18 UNITS DISTRIBUTED AMONG 2 OR 3 AIRLINES. IT IS CLEAR THAT INTERESTING WORK IS IN STORE FOR MANY OF US.

ALTIMETRY IS A CURRENT TOPIC. IT IS IMPORTANT FOR TCAS , IT IS IMPORTANT TO OUR EFFORT TO REDUCE VERTICAL SEPARATION ABOVE FL-290 TO 1000 FEET, AND IT IS IMPORTANT IF WE ARE TO IMPROVE CONTROLLER PRODUCTIVITY THROUGH THE APPLICATION OF AUTOMATION TO ROUTINE ATC FUNCTIONS. AT LEAST THREE COMMUNITY COMMITTEES ARE CURRENTLY WORKING ON VARIOUS ASPECTS OF ALTIMETRY, TWO COMMITTEES IN RTCA AND ONE SAE COMMITTEE. THE FAA IS INITIATING A COMPREHENSIVE REVIEW OF ALTIMETRY STANDARDS AND PRACTICES WITH THE OBJECTIVE OF IDENTIFYING OPPORTUNITIES FOR IMPROVING SYSTEM PERFORMANCE. WE EXPECT TO FOCUS INITIALLY ON AIRMAN EDUCATION PROGRAMS DESIGNED TO INCREASE AWARENESS OF SOUND ALTIMETRY PRACTICES. DATA COLLECTION PROGRAMS WILL BE INITIATED TO DEVELOP A BETTER UNDERSTANDING OF ALTIMETRY SYSTEM PERFORMANCE. IN ADDITION, WE WILL WANT TO WORK WITH THE COMMUNITY TO IDENTIFY OPPORTUNITIES FOR IMPROVED PERFORMANCE, BOTH OVER THE NEAR TERM AND OVER THE MORE DISTANT FUTURE. WE DO NOT INTEND TO PROPOSE NEW RULES NOR ARE WE SUGGESTING RADICAL DEPARTURES FROM THE STANDARDS AND PRACTICES THAT HAVE SERVED US UP TO NOW. HOWEVER, AS WE MODERNIZE THE AIRSPACE AND SEEK IMPROVEMENTS THROUGH AUTOMATION, IT IS TIMELY TO REVIEW ALTIMETRY AND TO SEEK IMPROVEMENTS WHERE THEY ARE WARRANTED. BEFORE I LEAVE THIS TOPIC, AND BEFORE SOMEONE ASKS THE QUESTION, I WILL SAY PLAINLY THAT WE DO NOT VIEW ALTIMETRY IMPROVEMENTS AS A PREREQUISITE FOR THE IMPLEMENTATION OF TCAS II.

FINALLY, I WANT TO MENTION THE ARINC CHARACTERISTIC FOR MINIMUM TCAS II. WE ARE AWARE THAT THE AIRLINES ELECTRONIC ENGINEERING COMMITTEE HAS DRAFTED CHARACTERISTICS FOR TCAS II, AND THAT A PRINCIPAL ITEM OF BUSINESS AT THE AEEC GENERAL SESSION IN NOVEMBER IS THE ADOPTION OF AN ARINC CHARACTERISTIC. WE BELIEVE THAT ADOPTING A CHARACTERISTIC NOW IS IN THE BEST INTERESTS OF OUR COMMUNITY. THE MINIMUM TCAS II IS VERY NEARLY READY TO GO, AND THE LACK OF A CHARACTERISTIC WILL IMPEDE AN IMPLEMENTATION. MOREOVER, THE FAA WOULD LIKE TO HAVE AN ADOPTED CHARACTERISTIC TO USE IN OUR PROCUREMENT OF AVIONICS UNITS FOR THE LIMITED DEPLOYMENT PROGRAM.

I WILL MAKE WAY NOW FOR KEN HUNT WHO WILL DISCUSS THE STATUS OF OUR OPERATIONAL EVALUATION ACTIVITIES AS VIEWED FROM THE OFFICE OF FLIGHT OPERATIONS.

THANK YOU FOR YOUR ATTENTION.

OPERATIONAL EVALUATION ACTIVITES

KENNETH S. HUNT
TCAS SYMPOSIUM
OCTOBER 12 - 13, 1982

IT IS A PLEASURE TO HAVE THE OPPORTUNITY TO SAY A FEW WORDS ABOUT TCAS II AND TO DISCUSS THE CONTINUING OPERATIONAL EVALUATION ACTIVITY ASSOCIATED WITH THIS EQUIPMENT.

IT HAS NOT BEEN EASY TO GET WHERE WE ARE TODAY, AND I WOULD LIKE TO COMPLIMENT THE MANY DEDICATED PEOPLE FROM THE ENGINEERING SIDE OF FAA, MIT LINCOLN LABORATORY, MITRE CORPORATION, AND INDUSTRY WHO, THROUGH RTCA, AEEC, AND OTHER DEVELOPMENTAL ACTIVITIES, HAVE PUT FORTH A TREMENDOUS EFFORT IN THE TECHNICAL DEVELOPMENT OF TCAS II. ALTHOUGH THIS EFFORT IS NOT COMPLETE, WE ARE ENCOURAGED BY WHAT WE HAVE SEEN TO DATE AND BELIEVE THAT TCAS IS A SYSTEM THAT HAS THE POTENTIAL TO PERFORM AN EFFECTIVE ROLE AS A BACKUP TO THE ATC SYSTEM.

AS THE TECHNICAL DEVELOPMENT NEARS COMPLETION, I THINK IT WOULD BE WORTHWHILE TO MAKE SOME GENERAL COMMENTS REFLECTING OUR VIEW OF TODAY'S TCAS II AND HOW THIS SYSTEM MIGHT BE OPERATIONALLY USED.

FROM OUR EXPERIENCE TO DATE IN THE OPERATIONAL EVALUATION EFFORT, AND PARTICULARLY FROM THE PIEDMONT AIRLINES DATA, I BELIEVE IT IS EVIDENT THAT TCAS DOES HAVE THE POTENTIAL TO PERFORM AN IMPORTANT ROLE IN THE EVOLVING NATIONAL AIRSPACE SYSTEM. THERE IS CERTAINLY SOME ADDITIONAL WORK TO BE

DONE, BUT OVERALL WE BELIEVE THAT TCAS II IS CAPABLE OF PROVIDING ADDED SEPARATION ASSURANCE BENEFITS WITHOUT SIGNIFICANTLY DISRUPTING EITHER THE COCKPIT OR THE ATC SYSTEM.

AL ALBRECHT MENTIONED A COMPREHENSIVE SYSTEM SAFETY STUDY TO ADDRESS ABRUPT INTRUDER MANEUVERS, ALTIMETRY ERRORS, AND UNDETECTED EQUIPMENT FAILURES. THESE ITEMS ARE OF CONCERN TO US SINCE WE DO NOT KNOW IF, OR HOW OFTEN, INCORRECT RESOLUTION COMMANDS COULD BE DISPLAYED. BECAUSE OF THESE CONCERNS WE DO NOT BELIEVE THAT TCAS II CAN BE IMMEDIATELY USED AS A PURE "FOLLOW THE ARROW" OR "EXECUTIVE" SYSTEM IN ALL WEATHER CONDITIONS. WE ARE CONFIDENT, HOWEVER, THAT THE SYSTEM WILL DEVELOP TO THE POINT WHERE THIS WILL BE POSSIBLE.

IT WAS MENTIONED EARLIER THAT A PILOT MAY NOT WISH TO FOLLOW A RESOLUTION ADVISORY BECAUSE OF OTHER INFORMATION THAT TELLS HIM THAT A MANEUVER IS UNNECESSARY. I THINK IT IS APPARENT FROM THE ADVISORIES WE HAVE SEEN THAT IN MANY CASES, TCAS WILL CALL FOR A MANEUVER THAT, ALTHOUGH CORRECT, IS INAPPROPRIATE OR UNNECESSARY GIVEN THE PILOT'S VISUAL UNDERSTANDING OF THE SITUATION.

WHERE DOES THIS TAKE US PROCEDURALLY? FOR THE REMAINING AIR CARRIER EVALUATION WORK, IT IS OUR INTENT TO TAKE A VERY CONSERVATIVE APPROACH UNTIL MORE DATA IS COLLECTED AND THE FULL POTENTIAL OF TCAS IS CLEARLY

UNDERSTOOD. THE INITIAL PROCEDURES MOST PROBABLY WILL CALL FOR THE PILOT TO FOLLOW A RESOLUTION ADVISORY ONLY IF HE HAS A VISUAL ACQUISITION CONFIRMING THAT THE MANEUVER IS CORRECT AND APPROPRIATE. THE NEXT STEP WILL BE BASED ON WHAT WE LEARN ABOUT TCAS IN AN OPERATIONAL ENVIRONMENT WHILE USING THESE RESTRICTIVE PROCEDURES. WHILE WE NEED TO BE PRUDENT IN OUR TESTS, WE INTEND TO AGGRESSIVELY MOVE FORWARD TAKING FULL ADVANTAGE OF THE FULL COLLISION AVOIDANCE POTENTIAL OF TCAS IN AN EVOLUTIONARY MANNER.

I WOULD LIKE TO REVIEW QUICKLY WHAT HAS BEEN ACCOMPLISHED DURING THE OPERATIONAL EVALUATION EFFORT AND WHAT WE SEE AS THE MAJOR REMAINING TASKS. PLEASE BEAR IN MIND THAT AS THESE TESTS PROCEED WE ARE WORKING TOWARDS THE DEVELOPMENT OF A CANDIDATE TCAS II SYSTEM TO DEMONSTRATE THE CAPABILITIES OF THE SYSTEM IN A REALISTIC AIR CARRIER ENVIRONMENT.

A YEAR AGO SEVERAL OPERATIONAL ISSUES WERE IDENTIFIED THAT MUST BE ANSWERED PRIOR TO THE IMPLEMENTATION OF TCAS. THESE ISSUES WERE:

- IDENTIFICATION OF MINIMUM RESOLUTION ADVISORY DISPLAY ELEMENTS.

- UTILITY OF BEARING/PROXIMITY INFORMATION.

- RESOLUTION OF COCKPIT WORKLOAD ISSUES.

- ESTABLISHING OPERATIONAL PROCEDURES.

- DEMONSTRATION OF SATISFACTORY DESENSITIZATION SCHEMES.

- DEMONSTRATION OF SATISFACTORY OPERATIONAL PERFORMANCE.

RESOLUTION ADVISORY DISPLAY ELEMENTS

AT THE DEVELOPMENTAL SIMULATION AT BOEING, THREE METHODS OF PRESENTING RESOLUTION ADVISORIES WERE INVESTIGATED.

1. A MODIFIED VERTICAL SPEED INDICATOR;
2. A LIGHT EMITTING DIODE (LED) DISPLAY WITH GRAPHICS AND ALPHANUMERICS; AND
3. A VOICE ONLY FORMAT.

BASED ON THIS WORK AND OTHER TEST EXPERIENCE, WE HAVE DECIDED TO USE THE MODIFIED VERTICAL SPEED INDICATOR FOR THE REMAINING TESTS. THIS INSTRUMENT HAS THE ADVANTAGE OF ALLOWING THE PILOT TO INTEGRATE THE VERTICAL GUIDANCE FROM TCAS WITH THE VERTICAL SPEED OF THE AIRCRAFT THROUGH THE USE OF ONE CONVENTIONAL INSTRUMENT. AS MOST OF YOU KNOW, THE MODIFICATION TO THIS INSTRUMENT IS THE ADDITION OF VERTICAL ARROWS FOR CLIMB/DESCENT ADVISORIES AND EYEBROW LIGHTS FOR NEGATIVE (I.E., DO NOT CLIMB/DIVE) AND LIMIT ADVISORIES.

OUR USE OF THIS INSTRUMENT HAS SHOWN THAT PILOTS EASILY UNDERSTAND THE INFORMATION PRESENTED AND THAT SIMPLE STRAIGHTFORWARD PROCEDURES ARE POSSIBLE USING THE ARROWS AND EYEBROW LIGHTS. THERE ARE CERTAINLY OTHER METHODS OF DISPLAYING RESOLUTION ADVISORIES THAT MAY BE EFFECTIVE, BUT FOR THE REMAINING TESTS WE INTEND TO STAY WITH THE MODIFIED VERTICAL SPEED INDICATOR AND DO NOT ANTICIPATE ANY SIGNIFICANT CHANGES TO THE CURRENT FORMAT.

BEARING/PROXIMITY INFORMATION

AS THE OPERATION/EVALUATION CONTINUES, WE ARE ATTACHING MORE AND MORE IMPORTANCE TO THE TRAFFIC ADVISORY FEATURE OF TCAS II. WE ARE FINDING THAT THIS INFORMATION PROVIDES A VITAL INTERFACE BETWEEN TCAS AND ATC AND SERVES TO PREPARE THE PILOT FOR A POSSIBLE RESOLUTION ADVISORY. IT ALSO ALLOWS A PILOT TO QUICKLY AND EASILY CORRELATE TCAS INFORMATION WITH HIS VISUAL PICTURE.

THE DISPLAY OF TRANSPONDER-EQUIPPED AIRCRAFT WITHOUT THE ALTITUDE REPORTING CAPABILITY (NON-MODE C), WHEN CERTAIN RANGE CRITERIA ARE MET, IS ANOTHER IMPORTANT CAPABILITY AVAILABLE THROUGH THE TRAFFIC ADVISORY FUNCTION. SINCE THIS APPEARS TO BE THE ONLY WAY TO ACHIEVE ANY USEABLE MEASURE OF PROTECTION AGAINST NON-MODE C AIRCRAFT, WE BELIEVE IT IS A VERY IMPORTANT FEATURE. ALTHOUGH OUR WORK WITH NON-MODE C ADVISORIES HAS BEEN LIMITED, WE ARE VERY ENCOURAGED BY THE INITIAL RESULTS.

AGAIN, SEVERAL DIFFERENT DISPLAY FORMATS AND INFORMATIONAL ELEMENTS HAVE BEEN EVALUATED AT BOEING AND IN OTHER TESTS. PILOT PREFERENCE HAS POINTED TOWARDS THE SIMPLE GRAPHICAL DISPLAY WE ARE USING WITH THE CANDIDATE SYSTEM. TO DATE, PILOTS HAVE FOUND THAT INFORMATION DISPLAYED IN THE MANNER YOU WILL SEE AT THE LINCOLN LABORATORY EXHIBIT HAS BEEN EASY TO USE AND INTERPRET.

THERE IS STILL SOME ADDITIONAL WORK TO BE DONE IN THIS AREA. CURRENTLY, WE ARE PROVIDING PROXIMITY TRAFFIC, ($\pm$ 1,200 FEET, 2 MILE RADIUS) TO THE PILOT WHEN A THREAT TRIGGERS THE DISPLAY TO ENSURE THAT A MIS-IDENTIFICATION DOES NOT OCCUR BETWEEN THE THREAT AND A PROXIMATE AIRCRAFT. SOME OF THE QUESTIONS RELATED TO THIS FEATURE ARE: SHOULD THIS PROXIMITY INFORMATION BE TRIGGERED OR DISPLAYED CONTINUOUSLY? ARE THE VALUES WE ARE USING FOR DISPLAYING PROXIMITY AIRCRAFT CORRECT? WILL THE PILOT BE ALLOWED TO RECEIVE PROXIMITY INFORMATION ON DEMAND OR SHOULD THIS FUNCTION BE AUTOMATED? ONCE THESE QUESTIONS ARE ANSWERED, IT MUST THEN BE DEMONSTRATED THAT THIS CAPABILITY WILL NOT BE MISUSED IN THE AIR CARRIER COCKPIT.

WE WELCOME, OF COURSE, INDUSTRY VIEWS ON THIS APPROACH TO THE DISPLAY OF RESOLUTION AND TRAFFIC ADVISORIES AND DO NOT, BY ANY MEANS, INPLY THAT WE WILL REJECT OTHER DESIGNS FOR THE PRESENTATION OF TCAS INFORMATION. WE WANT - AND ENCOURAGE - INNOVATION BY INDUSTRY.

COCKPIT WORKLOAD ISSUES

THE WORKLOAD ISSUE MUST STILL BE RESOLVED. SIMULATOR WORK AT BOEING USING A B-737 SIMULATOR IS DESIGNED TO STUDY THE IMPACT OF TCAS ON COCKPIT DUTIES, AND WE WILL ALSO BE EVALUATING WORKLOAD DURING THE OTHER TESTS.

GIVEN THE FREQUENCY AND NATURE OF THE ADVISORIES EXPERIENCED IN PHASE I OF THE PIEDMONT EVALUATION, WE DO NOT ANTICIPATE ANY MAJOR DIFFICULTIES WITH THE INTRODUCTION OF TCAS INTO THE COCKPIT, BUT IT MUST BE DEMONSTRATED THAT THIS IS TRUE. THE ALERTS AND WARNINGS ASSOCIATED WITH TCAS IS ANOTHER EVALUATION AREA WHERE ADDITIONAL WORK IS REQUIRED. SOME EXCELLENT PROGRESS WAS MADE AT BOEING FOR AN EXECUTIVE SYSTEM, AND WE MAY NEED TO MODIFY THESE RECOMMENDATIONS IN VIEW OF OUR CURRENT APPROACH TO THE OPERATIONAL DEMONSTRATION.

OPERATIONAL PROCEDURES

BASED ON THE INFREQUENT OCCURRENCE OF TCAS ADVISORIES, WE KNOW THAT THE OPERATIONAL PROCEDURES MUST BE STRAIGHTFORWARD AND SIMPLE. WE HAVE TAKEN A FIRST CUT AT PROCEDURES FOR BOTH THE TRAFFIC AND RESOLUTION ADVISORIES, AND ALTHOUGH OUR EXPERIENCE HAS BEEN LIMITED, WE HAVE PUT THEM TO USE WITHOUT DIFFICULTY. WE BELIEVE THAT SIMULATION AND INPUT FROM THE REMAINING TESTS WILL PROVIDE A USABLE SET OF PROCEDURES FOR USE IN THE AIR CARRIER DEMONSTRATIONS.

DESENSITIZATION

WE HAVE YET TO DEMONSTRATE A SATISFACTORY MEANS OF DESENSITIZING TCAS IN A MANNER THAT WILL ELIMINATE UNWANTED GROUND TARGETS. A TECHNIQUE WHICH COULD SUPPRESS AIRCRAFT ON THE GROUND HAS BEEN DEVELOPED BUT HAS NOT BEEN OPERATIONALLY TESTED. FROM THE HIGH PERCENTAGE OF UNDESIRABLE RA'S AND TA'S DURING THE PIEDMONT EVALUATION, IT IS APPARENT THAT PRIORITY MUST BE GIVEN TO SOLVING THIS PROBLEM.

OPERATIONAL PERFORMANCE

IF WE ARE TO IMPLEMENT TCAS ON A WIDE SCALE, BROAD EXPERIENCE WITH THE SYSTEM IN DAY TO DAY, REAL WORLD OPERATIONS IS IMPORTANT. IT IS APPARENT FROM THE LIMITED DATA THAT WAS ACCUMULATED FROM OVER 900 HOURS OF FLIGHT AT PIEDMONT THAT OPERATIONAL EXPERIENCE ACCUMULATES SLOWLY. WITH THE INCREASED NUMBER OF UNITS THAT WILL NOW BE PLACED ON SEVERAL DIFFERENT AIRLINES, I BELIEVE WE WILL RAPIDLY GAIN THE MORE EXTENSIVE BACKGROUND WE ALL NEED TO TRULY JUDGE THE OPERATIONAL EFFECTIVENESS OF TCAS II.

IN SUMMARY, A SUBSTANTIAL AMOUNT OF PROGRESS HAS BEEN MADE OVER THE LAST YEAR, MUCH OF WHICH IS A DIRECT RESULT OF COMMUNITY INVOLVEMENT IN THE DEVELOPMENT PROCESS. AS THE TECHNICAL DEVELOPMENT NEARS COMPLETION, WE HAVE REACHED A POINT THAT WILL REQUIRE EVEN GREATER INVOLVEMENT BY OPERATORS, PILOT GROUPS, MANUFACTURERS, AND OTHERS IN INDUSTRY TO ASSURE THE TCAS PROGRAM PROVIDES A DESIRABLE SYSTEM THAT WILL MEET THE COMMUNITY'S NEEDS.

WE ARE CLOSE TO HAVING A CANDIDATE TCAS II SYSTEM IN HAND AND HAVE MODIFIED THE PROGRAM TO ENLARGE THE QUANTITY AND QUALITY OF OPERATIONAL EXPERIENCE. AS WE PROCEED FROM THIS POINT, INPUT AND EXPERTISE FROM THE COMMUNITY IS ESSENTIAL IN DETERMINING THE PROPER ROLE FOR TCAS IN THE NAS.

THANK YOU.

TCAS PROGRAM

Dr. Clyde A. Miller
October 12, 1982

Program Engineering and Maintenance Service
Federal Aviation Administration
Washington, D. C. 20591

TCAS Concept

Before describing TCAS program activities, it is useful to take a moment to review the concept. The essence of the TCAS concept is the provision of a separation assurance capability that is able to operate throughout the airspace without reliance on ground equipments. TCAS, like it's predecessor BCAS (Beacon Collision Avoidance System), is based on the interchange of beacon, or secondary surveillance radar, signals among aircraft. The TCAS concept envisions a range of capabilities to include TCAS I, a low cost alternative, and TCAS II which is intended to provide a comprehensive level of separation assurance in all airspace.

TCAS II

TCAS II is further distinguished as either the Minimum TCAS II or the Enhanced TCAS II. Minimum TCAS II is capable of providing resolution advisories in the vertical plane (climb, descend) in airspace densities up to 0.3 aircraft per square nautical mile (or approximately 24 aircraft within 5 nautical miles of the TCAS II aircraft). Traffic advisories on nearby aircraft include the clock position, or bearing, of the intruding aircraft. The Minimum TCAS II uses the Mode S data link to transmit advisories to nearby TCAS I aircraft. These cross-linked advisories provide the position of the TCAS II aircraft as seen from the TCAS I aircraft. The Mode S air-to-air data link is also used to coordinate escape maneuvers among TCAS II aircraft that are in conflict.

It is important to ensure that the secondary surveillance radar signals transmitted by TCAS II avionics do not degrade the ability of ground-based ATC radars to sense traffic. In particular, the National Standard for TCAS II includes interference limiting algorithms that are designed to ensure that the ability of ground secondary surveillance radars to receive replys in response to interrogations is reduced by no more than 2 percent as a result of TCAS II operation.

The phrase "Enhanced TCAS II" denotes the use of more accurate intruder bearing data for the reduction of unnecessary alarms through miss distance filtering and for generating horizontal resolution advisories (turn right, turn left).

TCAS I

As a minimum, TCAS I has the ability to receive and display the traffic advisories crosslinked by TCAS II and has the ability to sense the presence of nearby aircraft by detecting their secondary surveillance radar transmissions (replies) at 1090 MHz. The replies detected may have been elicited by ground station interrogations (passive TCAS I) or may have resulted from low power interrogations from TCAS I (active TCAS I). Enhancements of TCAS I can take many forms to include the use of on board direction finding antennas to enhance the information obtained through listening for transponder replys.

Both TCAS I and TCAS II have integral transponders capable of operating on Modes A, C, and S (ie., Mode S transponders). These transponders not only support air-to-air Mode S data link operations necessary for TCAS but also provide an air-to-ground Mode S data link capability.

Program Activity Areas

For purposes of the discussion that follows, TCAS program activities are divided into the categories listed here.

Surveillance Techniques

Minimum TCAS II incorporates signal processing techniques whereby intruder aircraft can be tracked in high traffic densities. A principal technique is the use of directional antennas to transmit interrogations in relatively limited azimuth sectors thereby reducing the number of aircraft replying to each interrogation.

Direction finding antennas are under development at two levels. At Lincoln Laboratory and Dalmo Victor, relatively simple antennas have been developed and tested to provide intruder bearing for the traffic advisory function of Minimum TCAS II. A more sophisticated antenna appropriate for Enhanced TCAS II is under development at Bendix Corporation.

A final report describing transponder detection techniques, both passive and active, has been published.

Logic Development

The TCAS II threat detection and resolution logic is the set of computer algorithms which declare proximate aircraft to be collision threats or nonthreats, and which select the TCAS II avoidance maneuver advisories (resolution advisories) for those intruders declared collision threats. This logic also provides the rules whereby proximate aircraft are selected for the traffic advisory display.

The Minimum TCAS II logic is highly refined as a result of several years of intensive development. Current efforts to complete the development are focused on fully understanding it's performance capabilities (through simulation, flight test, and operational evaluation) and on adapting logic parameters to the environment in which TCAS will operate. The principal areas related to logic adaptation are assuring that adequate provisions are made for aircraft climb limitations and for altimetry errors that may be encountered in the airspace.

System Safety Study

The Minimum TCAS II surveillance and logic designs are now well established. We are very close to a full understanding of the capabilities and limitations of Minimum TCAS II to include limitations which are imposed by the environment in

which the system will operate. The system safety study will analyze the operation of TCAS in the environment to assess the performance of candidate flight operations procedures.

Engineering Model Fabrication and Test

Several engineering models of TCAS II equipments have been fabricated and tested, and more are coming. The Lincoln Laboratory Basic Experimental Unit (BEU) was tested throughout calendar year 1980 with excellent results. The tests included engineering evaluations of technical performance, collision resolution capabilities in intentional close encounters and limited operational evaluations in tours of the domestic airspace. Results were reported at our January 1981 BCAS Conference and are described in project reports.

The Dalmo Victor Omni TCAS units are modeled after the Lincoln Laboratory BEU design. The implementation is realized in a package substantially smaller than the BEU and includes a number of Dalmo Victor design innovations. These units were validated at the FAA Technical Center during 1981 and were installed in Piedmont Airlines aircraft for an evaluation of TCAS in the air carrier environment. The Dalmo Victor display units were not visible to the Piedmont crews. Display outputs were evaluated by observers riding in the jump seat.

The Lincoln Laboratory BEU has been modified to include the traffic advisory function of Minimum TCAS II. Engineering flight tests to assess the technical performance of this modification have been completed on both a Cessna 421 and the FAA Boeing 727 test aircraft.

One Dalmo Victor Omni TCAS unit has been modified by fitting an antenna that has a directional interrogation capability. The technical evaluation of this unit is scheduled for completion in November.

Dalmo Victor will deliver a fully functional Minimum TCAS II unit later this month. The unit incorporates essentially all of the features of Minimum TCAS II described in the draft Minimum Operational Performance Standards and is expected to be highly reliable. It has the capability to drive the cockpit traffic and resolution advisory displays currently envisioned for an air carrier. The latest version of the collision avoidance logic will be implemented in the unit along with the capability to generate traffic advisories on transponder equipped intruders that do not report altitude in their Mode C replies. The Dalmo Victor Minimum TCAS II unit will be used for the Phase II Piedmont in-service evaluation.

An Enhanced TCAS II engineering model based on the high performance antenna mentioned earlier is being designed and fabricated at Bendix for test and evaluation beginning in November 1982.

Operational Evaluation

As mentioned earlier, the Dalmo Victor Omni TCAS units were evaluated on in-service Piedmont air carrier aircraft. Our objective here was to assess the rate at which alarms occur in this environment, the air traffic circumstances which cause these alarms and the probable consequences of these alarms for normal air carrier operations.

We are also conducting cockpit simulations at Boeing Commercial Airplane Company. Phase I of this activity was oriented toward evaluating information display and alerting techniques in a developmental simulator. Phase II is focused on validating pilot procedures in a fully operational air carrier simulator.

The Lincoln Laboratory evaluations provide an opportunity to assess pilot interactions with TCAS II in the VMC environment. A Cessna 421 has been used as the test aircraft in order to reduce costs. Phase I evaluated pilot responses to several TCAS II alerting and display configurations. Phase II is focusing on pilot procedures in VMC.

The TCAS II validation in the FAA Boeing 727 aircraft will use the Dalmo Victor Minimum TCAS II unit with the pilot display configuration and procedures derived from the Boeing and Lincoln Laboratory evaluations. This activity is intended to validate and demonstrate the Minimum TCAS II concept in the operational air carrier context.

The Phase II Piedmont in-service evaluation will adapt the configuration validated in the FAA Boeing 727 aircraft to the Piedmont flight environment. Displays will be in operational use in accordance with the established procedures.

Limited Deployment

The FAA intends to support a limited operational deployment of Minimum TCAS II in order to provide the air carrier community operational experience with the use of the system. It is anticipated that 10 to 18 units will be procured and that two or more airlines will be equipped with these units.

Standards

This slide shows the schedule for generating standards related to TCAS I and TCAS II.

Conclusions

It is clear that a great deal of effort is being devoted to the development, evaluation, and demonstration of TCAS. We are confident that TCAS will provide an effective back-up separation assurance capability and expect user implementation in the United States to begin in 1984.

TCAS CONCEPT

AIRBORNE SEPARATION ASSURANCE EQUIPMENTS:

- o INDEPENDENT FROM GROUND EQUIPMENTS
- o BASED ON RADAR BEACON SIGNALING
- o RANGE OF CAPABILITIES

  TCAS I - LOW COST, LIMITED CAPABILITIES

  TCAS II - MAXIMUM PROTECTION FOR ALL ENVIRONMENTS

TCAS II

MINIMUM

- VERTICAL MANEUVERS
- RELIABLE OPERATION IN HIGH DENSITY AIRSPACE (24 AIRCRAFT WITHIN 5 NMI)
- TRAFFIC ADVISORIES INCLUDING INTRUDER BEARING
- CROSSLINK TRAFFIC ADVISORIES TO TCAS I; MANEUVER COORDINATION WITH TCAS II
- LESS THAN 2 PERCENT DEGRADATION OF GROUND SURVEILLANCE
- INTEGRAL MODE S TRANSPONDER WITH DATA LINK CAPABILITY

ENHANCEMENTS

- USE OF INTRUDER BEARING DATA FOR HORIZONTAL MISS DISTANCE ASSESSMENT (ALARM REDUCTION)
- USE OF INTRUDER BEARING DATA FOR HORIZONTAL RESOLUTION MANEUVERS

TCAS I

MINIMUM

- INTEGRAL MODE S TRANSPONDER WITH DATA LINK CAPABILITIY
- ABILITY TO RECEIVE AND DISPLAY ADVISORIES CROSSLINKED BY TCAS II
- ABILITY TO SENSE THE PRESENCE OF NEARBY AIRCRAFT BY DETECTING TRANSPONDER REPLIES

ENHANCEMENTS

- DIRECTION FINDING ANTENNA TO INDICATE BEARING OF PROXIMATE TRAFFIC DETECTED BY LISTENING FOR TRANSPONDER REPLIES

PROGRAM ACTIVITY AREAS

O SURVEILLANCE TECHNIQUES

O LOGIC DEVELOPMENT

O SYSTEM SAFETY STUDY

O ENGINEERING MODEL FABRICATION AND TEST

O OPERATIONAL EVALUATION

O LIMITED DEPLOYMENT

O STANDARDS

SURVEILLANCE TECHNIQUES

TCAS II

- 0 SIGNAL PROCESSING FOR HIGH DENSITY OPERATION
- 0 SECTORIZED INTERROGATION
- 0 DIRECTION FINDING AIRCRAFT ANTENNAS
- 0 DRAFT REPORT, JANUARY 1983

TCAS I

- 0 DETECTION OF PROXIMATE TRANSPONDERS
- 0 REPORT, SEPTEMBER 1982

LOGIC DEVELOPMENT

O PERFORMANCE VALIDATION

- DESENSITIZATION AND ALARM RATES
- ULTIMATE CAPABILITIES

O ADAPTATION OF LOGIC

- AIRCRAFT CLIMB CAPABILITIES
- NOMINAL ALTIMETRY ERRORS

O PRODUCTS

- DRAFT LOGIC DOCUMENT, OCTOBER 1982

SYSTEM SAFETY STUDY

- 0 OBJECTIVE: ESTABLISH OPERATIONAL PROCEDURES AND SAFETY OF TCAS II OPERATIONS
- 0 APPROACH: ANALYSIS USING EXISTING DATA BASES
  - UNDETECTED EQUIPMENT FAILURES
  - MANEUVERING INTRUDERS
  - ALTIMETRY ERRORS
- 0 MECHANICS: COMMUNITY INVOLVEMENT
- 0 SCHEDULE: OCTOBER 1982 - APRIL 1983

ENGINEERING MODEL FABRICATION AND TEST

- LINCOLN LABORATORY BASIC EXPERIMENTAL UNIT
  - FLIGHT TESTS, FEBRUARY - NOVEMBER 1980
  - FAA TECHNICAL CENTER REPORT 81-25, AUGUST 1981
  - FAA REPORT RD-80-138 (MITRE), JANUARY 1981
  - ACTIVE BCAS CONFERENCE, JANUARY 1981
- DALMO VICTOR OMNI TCAS UNIT
  - ENGINEERING FLIGHT TESTS, APRIL - OCTOBER 1981
  - FAA TECHNICAL CENTER REPORT, OCTOBER 1982
- LINCOLN LABORATORY ANGLE OF ARRIVAL UNIT
  - FLIGHT TESTS, OCTOBER 1981 - JUNE 1982
  - DRAFT REPORT, JANUARY 1983

ENGINEERING MODEL FABRICATION AND TEST

(CONTINUED)

O DALMO VICTOR SECTOR INTERROGATION UNIT

- FLIGHT TESTS, MAY-NOVEMBER 1982
- DRAFT REPORT, JANUARY 1983

O DALMO VICTOR MINIMUM TCAS II UNIT

- ENGINEERING FLIGHT TESTS, OCTOBER 1982 - MARCH 1983

O BENDIX ENHANCED TCAS II UNIT

- FLIGHT TESTS, NOVEMBER 1982 - APRIL 1984

OPERATIONAL EVALUATION

- o PIEDMONT AIRLINES IN-SERVICE EVALUATION (PHASE I)
  - IN-SERVICE EVALUATION, NOVEMBER 1981 - MARCH 1982
  - REPORT, OCTOBER 1982
- o BOEING COCKPIT SIMULATIONS (PHASES I AND II)
  - SIMULATION TESTS, DECEMBER 1981 - DECEMBER 1982
  - PHASE I REPORT, NOVEMBER 1982
  - PHASE II DRAFT REPORT, FEBRUARY 1983

OPERATIONAL EVALUATION (CONTINUED)

- LINCOLN LABORATORY IN-FLIGHT EVALUATIONS (PHASES I AND II)
  - FLIGHT TESTS, JANUARY - NOVEMBER 1982
  - PHASE I REPORT, SEPTEMBER 1982
  - PHASE II DRAFT REPORT, JANUARY 1983
- MINIMUM TCAS II VALIDATION (FAA BOEING 727)
  - IN-FLIGHT VALIDATION, APRIL- MAY 1983
- PIEDMONT AIRLINES IN-SERVICE EVALUATION (PHASE II)
  - IN-SERVICE EVALUATION, JUNE - OCTOBER 1983

STANDARDS

TCAS II

APRIL 1982	DRAFT NATIONAL STANDARD FOR MINIMUM TCAS II
JUNE 1982	DRAFT MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR MINIMUM TCAS II
JANUARY 1983	MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR MINIMUM TCAS II ADOPTED
FEBRUARY 1983	FINAL NATIONAL STANDARD FOR MINIMUM TCAS II PUBLISHED
JUNE 1984	DRAFT MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR ENHANCED TCAS II

TCAS I

SEPTEMBER 1982	MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR MODE S TRANSPONDER ADOPTED

LIMITED DEPLOYMENT

O OBJECTIVE: PROVIDE AIR CARRIERS OPERATIONAL EXPERIENCE WITH MINIMUM TCAS II

O APPROACH:

- PROCURE 10 TO 18 UNITS PER MOPS AND ARINC CHARACTERISTIC
- EVALUATE IN 2 OR MORE AIRLINES

O SCHEDULE GOAL:

- AVIONICS DELIVERY, MID 1984

CONCLUSIONS

- MUCH WORK HAS BEEN DEVOTED TO THE DESIGN AND EVALUATION OF TCAS

- NATIONAL IMPLEMENTATION IS EXPECTED TO BEGIN IN 1984

STATUS OF

MODE S IMPLEMENTATION

DOUGLAS HODGKINS

OCTOBER 12, 1982

PROGRAM ENGINEERING AND MAINTENANCE SERVICE
FEDERAL AVIATION ADMINISTRATION
WASHINGTON, DC. 20591

1 - PICTORIAL

ON SEPTEMBER 28 APPROVAL WAS GRANTED TO PROCEED WITH MODE S IMPLEMENTATION.

FOR THOSE OF YOU NOT FAMILIAR WITH MODE S, IT IS AN EVOLUTIONARY UPGRADING OF OUR PRESENT AIR TRAFFIC CONTROL RADAR BEACON SYSTEM OR ATCRBS. IT WILL PROVIDE IMPROVED AIRCRAFT POSITION AND INTERFERENCE FREE IDENTIFICATION AND ALTITUDE DATA, AND A NEW CAPABILITY TO COMMUNICATE DIGITALLY WITH THE AIRCRAFT VIA A DATA LINK. THE DATA LINK IS BOTH GROUND-TO-AIR AND AIR-TO-GROUND AND IS AN INTEGRAL PART OF THE SURVEILLANCE FUNCTION. MANY ATC AUTOMATION ENHANCEMENTS ARE POSSIBLE WITH THE DATA LINK CAPABILITY AS WELL AS OTHER SERVICES THAT I WILL DESCRIBE.

TWO CONTRACTS ARE PLANNED IN ACCORDANCE WITH THE NATIONAL AIRSPACE SYSTEM PLAN, THE FIRST FOR 137 SYSTEMS THAT WILL PROVIDE SURVEILLANCE AND DATA LINK COVERAGE ABOVE 12,500 FEET AND AT ALL MAJOR TERMINALS. THE SECOND FOLLOW-ON CONTRACT WILL PROCURE AN ADDITIONAL 60 SYSTEMS TO LOWER THE COVERAGE TO 6000 FEET.

2 - SYSTEM CONCEPT

THE USE OF MODE S TO SERVE ATC AND PROVIDE OTHER DATA LINK FUNCTIONS SUCH AS WEATHER DATA WILL BE CONFIGURED AS SHOWN ON THIS SLIDE. THE SURVEILLANCE FUNCTION OF COURSE IS A PRIMARY ATC REQUIREMENT AND NEEDS NO EXPLANATION, HOWEVER, THE ADDITION OF DATA LINK WILL PROVIDE ATC WITH A NEW CAPABILITY TO ENHANCE PRODUCTIVITY AND SAFETY. WE HAVE IDENTIFIED TWO AREAS WHERE BOTH PRODUCTIVITY AND SAFETY CAN BE GREATLY ENHANCED WITH THE INTRODUCTION OF MODE S. THEY ARE AUTOMATING SECTOR TO SECTOR HANDOFFS AND PROVIDING A BACK-UP TO VOICE CLEARANCES WITH VISUAL PRESENTATION VIA THE DATA LINK. ALSO SOME CLEARANCES MAY BE SUITABLE FOR DIRECT DELIVERY BY DATA LINK IN LIEU OF VOICE, RELIEVING CONTROLLERS FROM THESE ROUTINE TASKS SUCH AS PREDEPARTURE, FLIGHT PLAN AND TAKEOFF CLEARANCES.

INITIAL SERVICES OTHER THAN ATC FUNCTIONS ARE PLANNED SUCH AS MAKING WEATHER DATA AVAILABLE DIRECTLY TO THE PILOT IN THE COCKPIT UPON REQUEST.

THE INITIAL WEATHER PRODUCT LIST WILL INCLUDE SUCH ITEMS AS SURFACE OBSERVATIONS, TERMINAL FORECASTS AND WINDS ALOFT FORECASTS. THESE WILL BE AVAILABLE FROM THE FLIGHT SERVICE DATA PROCESSING SYSTEM AND CENTRAL WEATHER PROCESSOR IN THE SAME TIME FRAME AS THE FIRST STAGE OF MODE S IMPLEMENTATION. TYPICALLY, A PILOT WOULD INITIATE VIA A COMM B, A DOWNLINK REQUEST FOR WEATHER WHICH WOULD BE "READ" BY THE MODE S SITE HAVING SURVEILLANCE RESPONSIBILITY AND SENT VIA THE NATIONAL AIRSPACE DATA INTERCHANGE NETWORK TO THE APPROPRIATE FSDPS HAVING THE PARTICULAR WEATHER PRODUCTS REQUESTED. THIS NADIN NETWORK ALLOWS THE PILOT TO REQUEST WEATHER ANYWHERE IN THE U.S. AND ONCE THE PRODUCTS ARE LOCATED, WOULD BE SENT BACK OVER NADIN TO THE REQUESTING SENSOR FOR DELIVERY TO THE AIRCRAFT.

3 - ORGANIZATION

THE SERVICES THAT I JUST DESCRIBED WERE PLANNED AS PART OF THE NATIONAL AIRSPACE SYSTEM PLAN. AN INTERSERVICE WORKING GROUP FOR DATA LINK HAS BEEN ESTABISHED TO EVALUATE BENEFITS AND PRIORITIES FOR OTHER USES OF THE DATA LINK. THIS GROUP COMPOSED OF REPRESENTATIVES FROM THE AIR TRAFFIC SERVICE, THE NEW PROGRAM ENGINEERING SERVICE, NATIONAL AVIATION STANDARDS AND THE TECHNICAL CENTER WILL BE REVIEWING EACH CANDIDATE SERVICE AND DETERMINE IF THERE IS A DIRECT BENEFIT THAT EXCEEDS COST EITHER IN TERMS OF PRODUCTIVITY GAINS FOR ATC OR SAFETY OR BOTH. WHILE IT WOULD BE QUITE UNMANGEABLE TO INVITE EACH OF THE USER GROUPS AND AVIATION COMMUNITY REPRESENTATIVES TO PARTICIPATE DIRECTLY IN THE WORKING GROUP, WE DO WELCOME YOUR INPUTS. TO GET YOUR VIEWS CONSIDERED, I WILL BE YOUR FOCAL POINT AND REPESENTATIVE. PLEASE FEEL FREE TO SUBMIT ANY COMMENTS YOU HAVE DIRECTLY TO ME IN THE MODE S PROGRAM OFFICE.

4 - ADDITIONAL SERVICES

OTHER SERVICES BEING REVIEWED BY THE WORKING GROUP IN ADDITION TO THOSE I MENTIONED EARLIER HAVE BEEN IDENTIFIED AS POSSIBLE DATA LINK CANDIDATES. THESE INCLUDE SUCH SERVICES AS; MORE WEATHER PRODUCTS AS THEY BECOME AVAILABLE THROUGH WEATHER IMPROVEMENT PROGRAMS SUCH AS NEXRAD, DIGITAL TERMINAL INFORMATION SERVICES AND MINIMUM SAFE ALTITUDE WARNINGS.

THE AIRSPACE AND TRAFFIC ADVISORY SERVICE WAS MENTIONED IN THE NATIONAL AIRSPACE SYSTEMS PLAN AS A POSSIBLE CANDIDATE FOR EARLY IMPLEMENTATION. THIS SERVICE IS CURRENTLY BEING REVIEWED WITHIN THE FAA AND A RECOMMENDATION WILL BE MADE TO THE ADMINISTRATOR IN THE VERY NEAR FUTURE. IF THE DECISION IS TO IMPLEMENT ATAS, IT WILL BE AVAILABLE AS SOON AS THE SENSORS ARE INSTALLED AS THIS SERVICE HAS ALREADY BEEN DEVELOPED AND CAN BE IMPLEMENTED WITH MODE S GROUND STATIONS.

ATAS PROVIDES THE CAPABILITY TO ALERT PILOTS OF PROXIMITY TO SPECIAL USE AIRSPACE SUCH AS A RESTRICTED AREA AND PROVIDES UP TO 4 TRAFFIC ADVISORIES FOR COCKPIT DISPLAY. THE TRAFFIC ADVISORIES ARE SIMILAR IN CONTENT TO THOSE CURRENTLY PROVIDED TODAY BY THE CONTROLLER ON A WORKLOAD PERMITTING BASIS. THE ADVISORIES WILL BE UPLINKED IN PRIORITY ORDER. THAT IS, THE CLOSEST TRAFFIC IN TIME OR DISTANCE TO OWN AIRCRAFT WILL BE UPLINKED FIRST. A "CLEAR ADVISORY" WILL BE UPLINKED WHEN TARGET AIRCRAFT IS AT LEAST 2 NAUTICAL MILES FROM OWN AIRCRAFT OR CLEAR OF THE AIRSPACE. THE AVIONICS AND COCKPIT DISPLAYS FOR ATAS AND TCAS I ARE COMPATIBLE. THE ONLY DIFFERENCES ARE ATAS USES DIFFERENT DATA LINK FORMATS AND CONTAINS MORE INFORMATION THAN TCAS I. THEREFORE, A PILOT EQUIPPING WITH EITHER TCAS I OR ATAS CAN EQUIP WITH THE OTHER AT MINIMAL INCREASE IN AVIONICS COST.

5 - DATA LINK SCHEDULE

OUR CURRENT DATA LINK SERVICE IMPLEMENTATION SCHEDULE IS BASED ON THE DEPLOYMENT SCHEDULE FOR MODE S. A FINAL BASIC NATIONAL AVIATION STANDARD WILL BE PUBLISHED IN 1984, FOLLOWING A DRAFT IN EARLY 1983, WITH RTCA ACTIVITY STARTING IN 1983, A MOPS COULD BE AVAILABLE IN LATE 1984 AND A TSO IN 1985 ALLOWING MANUFACTURERS ADEQUATE TIME TO PROVIDE AVIONICS FOR A FIRST PACKAGE IMPLEMENTATION IN LATE 1987. AN ANNEX FOR THE FIRST SERVICE PACKAGE WOULD PROBABLY BE ISSUED WITH THE BASIC STANDARD. ANEXES WOULD THEREAFTER BE ISSUED AS NEEDED. IMPLEMENTATION OF PACKAGE II (WEATHER) IS CURRENTLY SCHEDULED FOR LATE 1988.

6 - TCAS

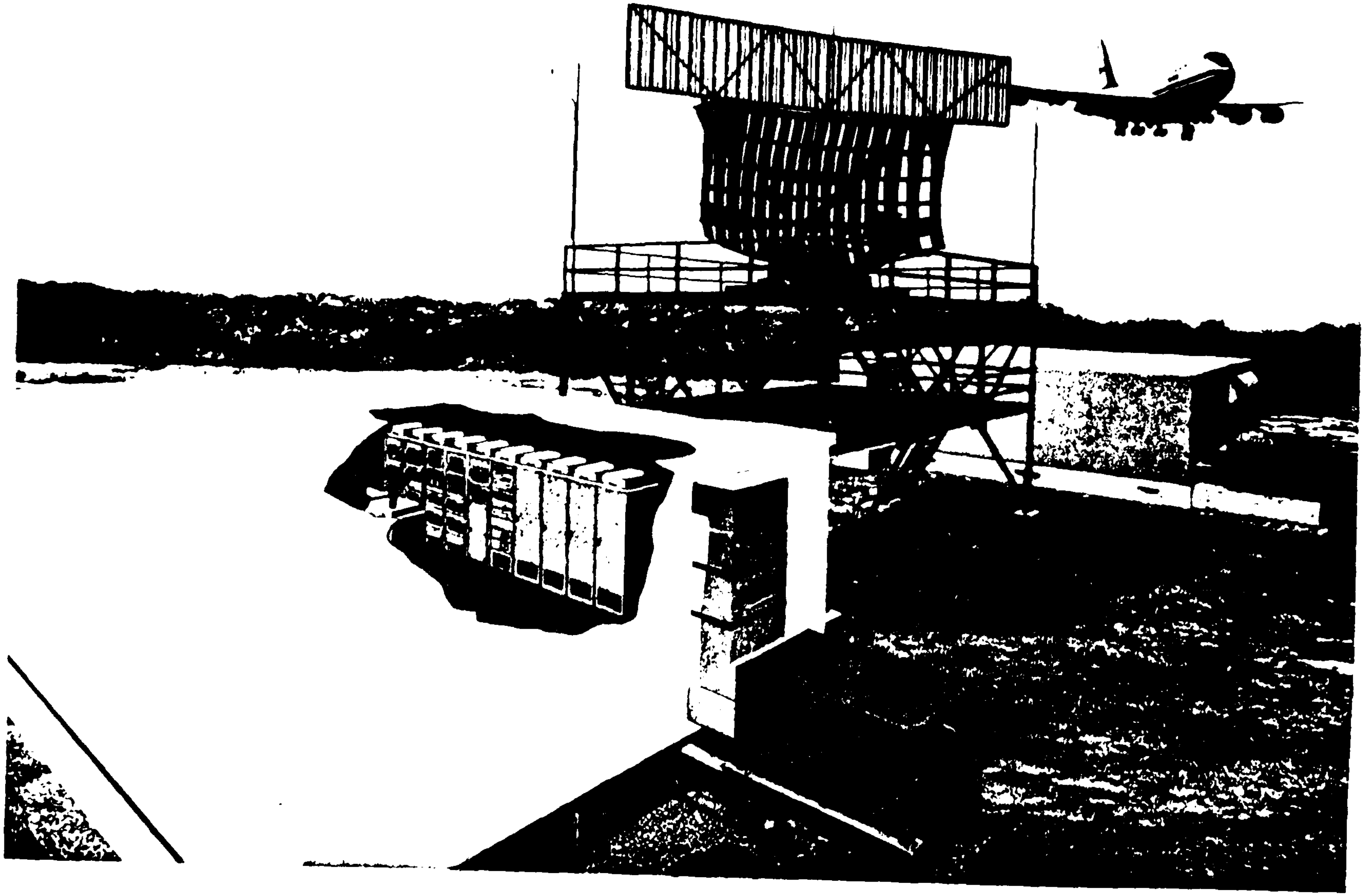
AS THIS IS THE THIRD TCAS SYMPOSIUM, YOU ARE WELL AWARE THAT TCAS IS USING THE MODE S DATA LINK FORMATS FOR CROSS-LINK COMMUNICATIONS BETWEEN TCAS EQUIPPED AIRCRAFT. THESE FORMATS ARE IN THE FINAL STAGE OF COORDINATION AND WILL SOON BE PUBLISHED IN THE MODE S NATIONAL AVIATION STANDARD AND FURTHER DETAILED AS TO THE CONTENT IN THE APPROPRIATE TCAS STANDARDS.
IN GENERAL, THERE WILL BE BOTH A SHORT SPECIAL SURVEILLANCE OF 56 BITS AND A LONG SPECIAL SURVEILLANCE OF 112 BITS FOR BOTH INTERROGATION AND REPLY. THE SHORT MESSAGES ARE INTENDED FOR USE WITH MINIMUM MODE S TRANSPONDERS AND, THE LONG MESSAGES PROVIDING MORE INFORMATION OF COURSE TO APPROPRIATELY EQUIPPED TCAS USERS. ALL MODE S AND MINIMUM TCAS UNITS WILL TRANSMIT A "SQUITTER" OR SHORT REPLY MESSAGE AT 1 SECOND INTERVALS. THIS IS USED AS YOU KNOW FOR TCAS ACQUISITION.

THATS THE EXTENT OF MODE S INVOLVEMENT IN TCAS.

National Airspace System Plan

- Replacement of enroute center computers
- Redesign of software
- Replacement of controller sector position equipment
- Automation of flight service facilities
- Major improvements to ground communication systems
- Implementation of Mode S and Data Link

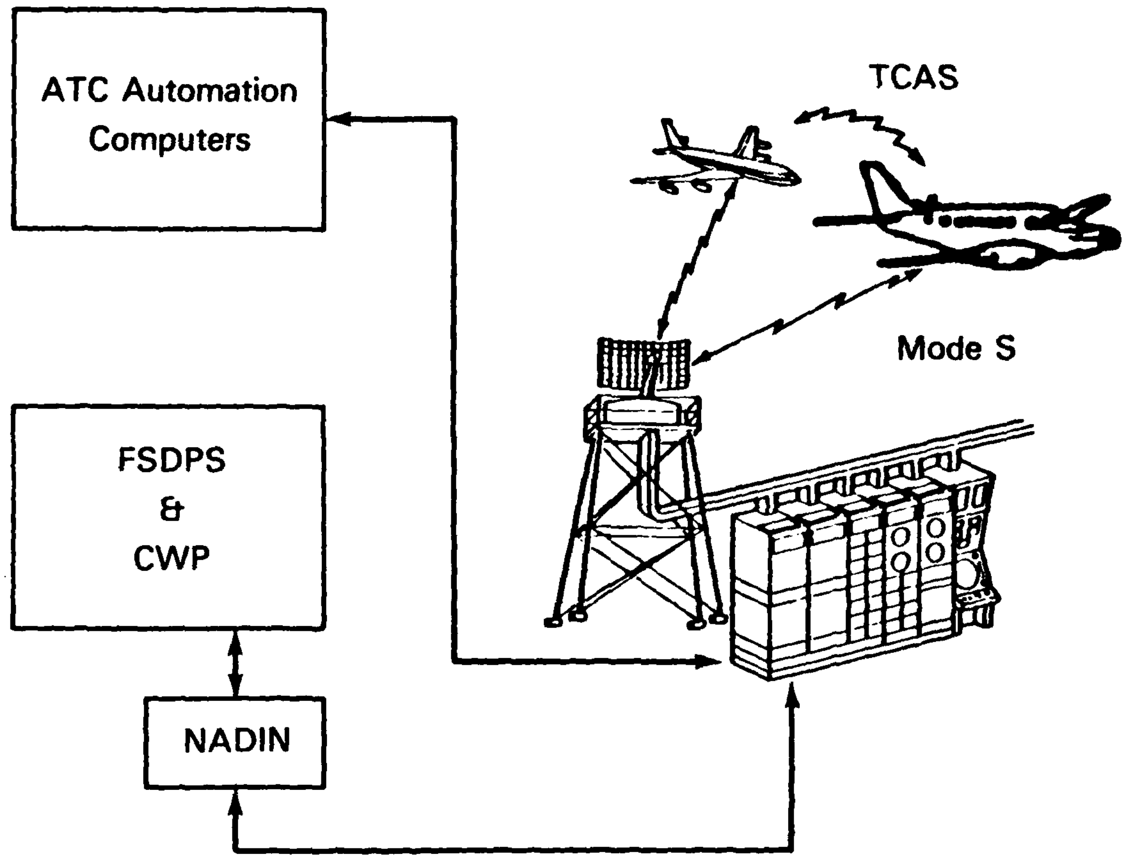
Mode S



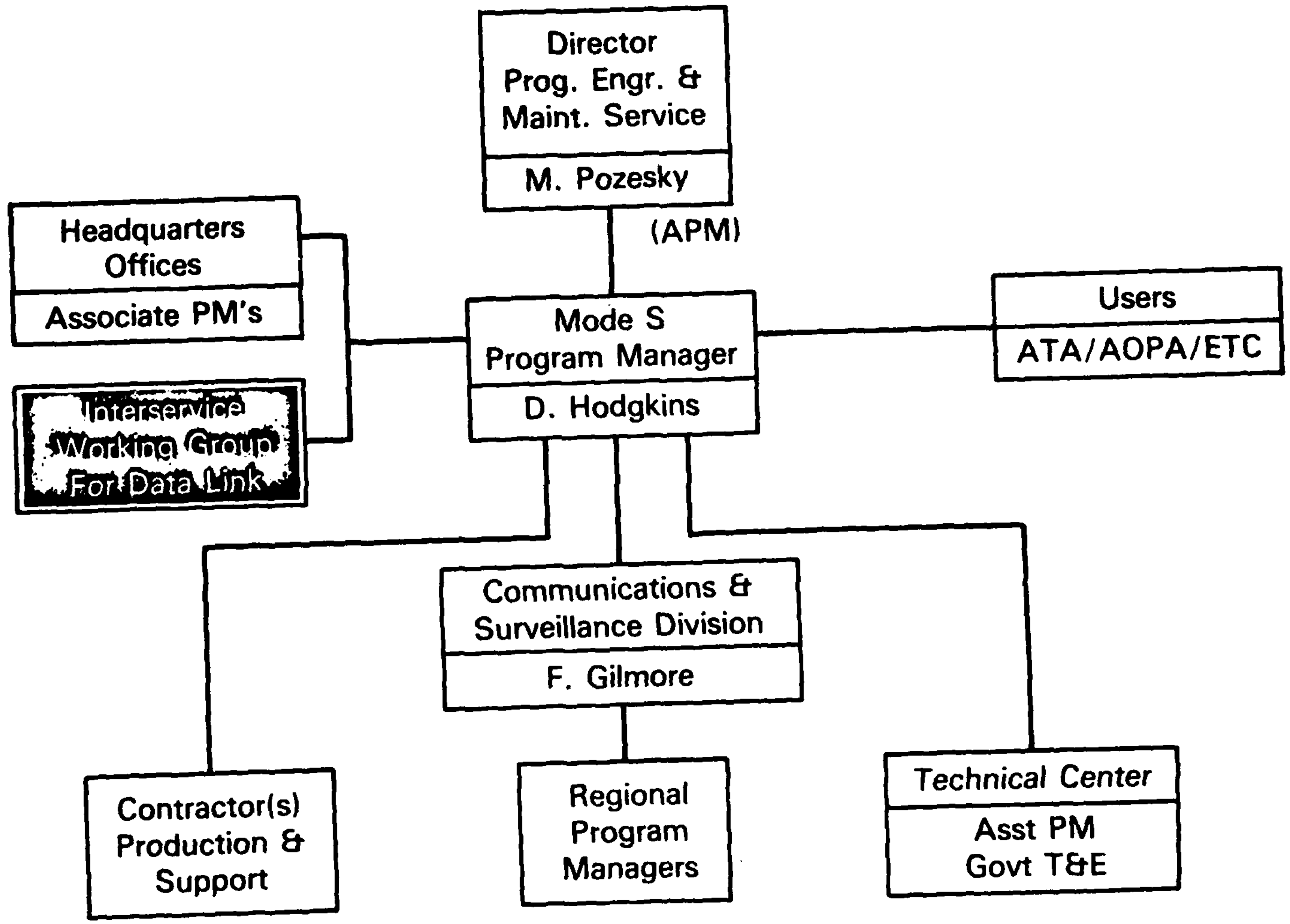
System Concept

ATC Services
- Sector Handoff
- Clearance Delivery
- Surveillance

Weather Services
- Surface Observations
- Terminal Forecasts
- Winds Aloft Forecasts



Organization



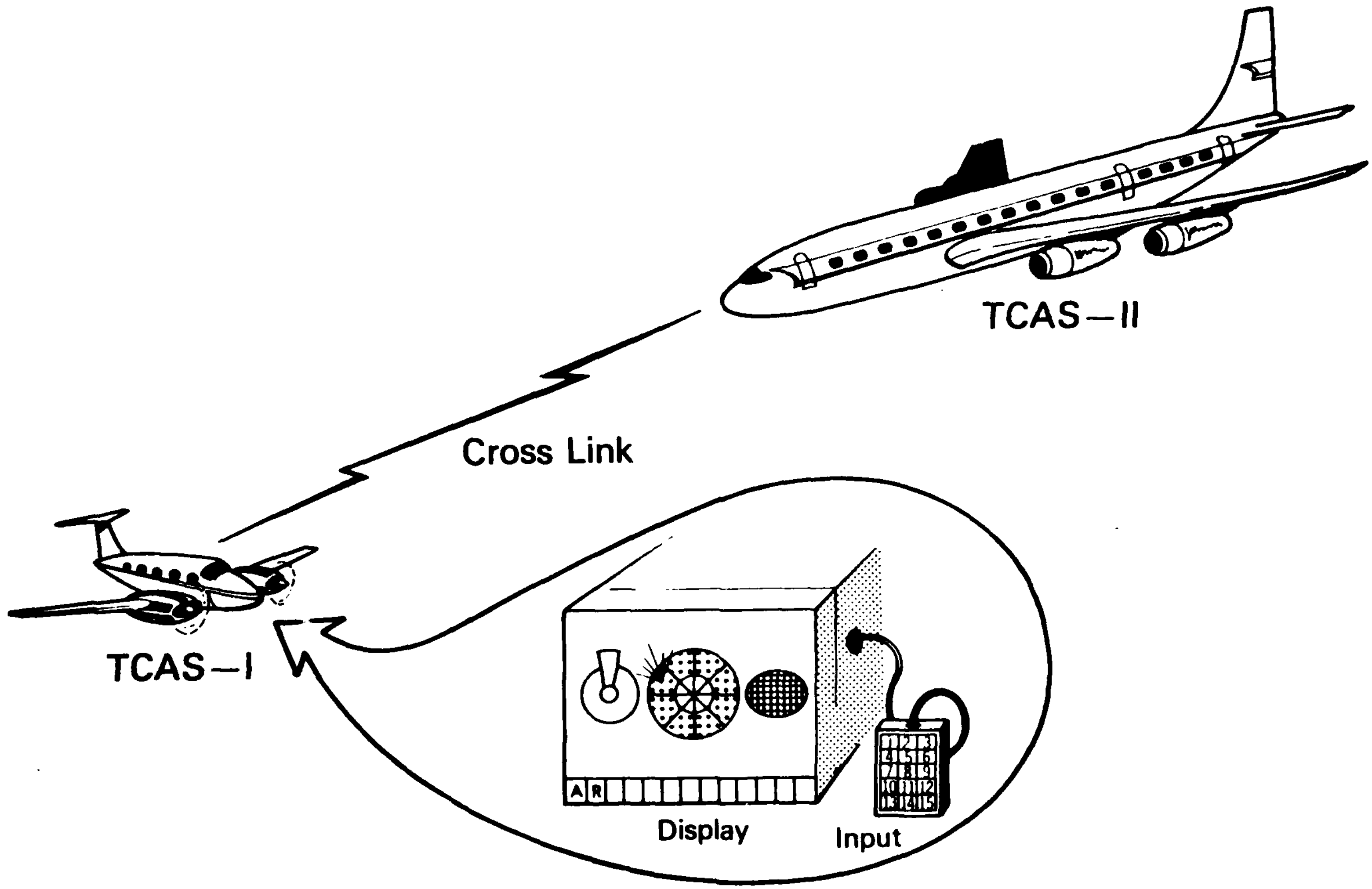
Additional Service Candidates

- Additional Weather Information
- Digital Terminal Services
- Flight Plan Clearance Delivery
- Takeoff Clearance Delivery
- Minimum Safe Altitude Warning
- Airspace and Traffic Advisory Service

Data Link Schedule

• National Standard	
— Draft	Early 1983
— Final	1984
— Annexes for service packages	As needed
• Package I implementation	Late 1987
• Package II implementation	Late 1988
• Additional packages	At 1—2 year intervals

Cross Link



TCAS II Operational Doctrine

Dr. Clyde A. Miller
October 12, 1982

Program Engineering and Maintenance Service
Federal Aviation Administration
Washington, D.C. 20591

We have accumulated a certain amount of operational experience with TCAS II from airspace tours in FAA test aircraft, subject pilot testing at Lincoln Laboratory and the Phase I Piedmont in-service evaluation. These results lead to certain conclusions with respect to the role of traffic advisories in airborne collision avoidance systems and with respect to flight crew response to resolution advisories. Our conclusions are not irrevocable but they are influencing our program plans.

Role of Traffic Advisories in TCAS II

Traffic advisories (TA's) are normally displayed 15 seconds (a logic parameter) prior to the display of resolution advisories (RA's). An early rationale for traffic advisories was to permit a flight crew to resolve an encounter conventionally prior to the time the RA is displayed. Conventional resolution can be achieved either through coordination with ATC or through see-and-avoid.

More recently, we have come to recognize that traffic advisories provide a critical link between conventional separation assurance techniques and the TCAS resolution advisory. Examples of this are discussed on the next few slides. The point is that the pilot may be discussing traffic with ATC or may have traffic in sight when TCAS displays a resolution advisory. Normally, it is important for the crew to know whether or not TCAS and the conventional information are concerned with the same traffic. If TCAS cannot display the range, altitude, and bearing of the traffic that generated the resolution advisory, correlation may be impossible.

Finally, intruder maneuvers, surveillance (e.g. altimetry) errors, and undetected failures in avionics (TCAS and intruder automatic altitude reporting equipment) all can degrade resolution performance. Where possible, it is important for the crew to visually confirm the resolution of the conflict, and the traffic advisory tells them where to look for the intruding aircraft.

A later talk by John Andrews will discuss the extent to which pilots appear to require traffic information for the reasons outlined above, the extent to which TCAS traffic advisories can provide the information needed and the extent to which pilots can be persuaded not to misuse the traffic information. The three examples that follow provide only an intuitive feeling for the role of the TA.

Alert in Visual Conditions

This encounter is similar to two that occurred during the Piedmont in-service evaluation. The illustration envisions that ATC has advised the TCAS crew of the intruder, the crew has acknowledged sighting the intruder, and ATC has permitted the crew to continue their climb when clear of the traffic. TCAS, of course, unaware of the agreement reached between ATC and the flight crew, senses the encounter and generates a "descend" advisory. Clearly the crew does not want to follow such an advisory with respect to the sighted aircraft. The only way to correlate the "descend" advisory with the visually acquired aircraft is through an appropriate TCAS traffic advisory.

Alert on Final Approach

A different type of encounter is also suggested by our Piedmont experience. In this case, ATC has called the traffic to include its altitude. The crew of the TCAS aircraft is searching for the traffic but has not found it. As the aircraft close, TCAS displays the traffic. Later, TCAS displays a "Do Not Descend" resolution advisory that permits own aircraft to level above the intruder and then resumes the approach. While the RA alone would have resolved the encounter, the TA reassured the crew that the RA pertained to the traffic called by ATC. Without the TA, the crew might be concerned that the RA pertained to a second intruder causing them to visually search for two aircraft while responding to the RA.

Alert Due to Maneuvering Intruder

The maneuvering intruder is perhaps the greatest limitation to the effectiveness of the resolution advisory. As illustrated, the intruder has been cleared to 16,000 feet but descends with a high vertical rate through 16,500 feet, overshoots his cleared altitude by 500 feet and finally reaches his assigned altitude. As the intruder descended through 16,500 feet, TCAS sensed the conflict, projected the intruder to pass below and issued a "climb" advisory. Five seconds prior to the closest point of approach in range (CPA), TCAS recognized that the climb advisory would not carry TCAS above the intruder and indicated that the RA was "Not OK." The example assumes that the TCAS pilot does not see the intruder and continues his 1500 fpm climb passing 200 feet below the intruder.

If the TCAS aircraft has a traffic advisory capability, this information will tell the crew where to look for the intruder in order to visually verify the resolution of the encounter.

While disucssing the effects of intruder maneuvers, it should be pointed out that such maneuvers are a factor in both the vertical and the horizontal planes. Hence a TCAS II with a horizontal resolution capability is not immune to this limitation.

Significance of Minimum TCAS II Advisories

The second part of this talk discusses the development of a doctrine for crew response to resolution advisories. It is important to recognize that TCAS advisories do not mean that the crew is about to experience a midair collision. In the Piedmont evaluation, we flew through 25 RA's without a close encounter or system error. A TCAS RA means that traffic is close by and indicates a maneuver that should increase separation. Hence, it is possible to ignore RA's without catastrophic results. In fact, if one applies the alert rate from our Piedmont evaluation (1 RA in 37 hours) to the accumulated hours flown by domestic air carriers since the San Diego midair collision in September 1978, a fully equipped air carrier fleet would have experienced 500,000 RA's over the time period. This simple statistic suggests that the probability of a collision, given that an RA is displayed, is less than 1 in 500,000.

Doctrine Options For Response to Resolution Advisories

There are three principal options:

(1) Always follow the RA,

(2) Follow unless other information (e.g., visual) indicates that response is unnecessary or inappropriate,

(3) Use option (2) except sometimes an RA may be ignored altogether.

In suggesting that some RA's may be ignored, it is recognized that the option is somewhat unattractive from a human factors point of view. Nonetheless, as pointed out earlier, an RA does not mean that a collision is about to occur.

Respone Versus No Response: Altimetry Errors

The following examples illustrate the relative risks inherent in either responding or not responding to displayed resolution advisories. The examples are based on an analysis of altimetry errors which can induce wrong way avoidance maneuvers as illustrated in this slide. The pressure altitude data available to TCAS from its own air data sources, and the Mode C reports from the intruder, indicate that the intruder is "seen" in close vertical proximity at CPA and passing slightly above TCAS. In order to increase vertical separation, TCAS selects a "descend" advisory. However, due to the effects of altimetry errors, the intruder seen to be passing above is actually passing below TCAS. As a result, the descend maneuver may decrease vertical separation at the closest point of approach in range (CPA) as opposed to increasing it. That is, it might have been better to not follow the RA. Notice, however, that not following the RA accepts the risk of close vertical proximity at CPA implicit in the "seen" position of the intruder.

Magnitudes of Altimetry Errors

In order to quantify the relative risks in responding and not responding in the presence of altimetry errors, some notion of the magnitudes of these errors is required. The air carrier performance tabulated here is thought to be representative of ARINC quality equipment installed as primary air data systems in the majority of U.S. air carrier aircraft (i.e., ARINC Characteristic 545 equipment). The general aviation performance shown is implied by Federal Aviation Regulations and a survey of static source performance based on pilot handbooks. The improved general aviation performance is extrapolated from the general aviation data by assuming better static source performance and a better correspondence between static system pressure and Mode C reported altitude.

Response Versus No Response Given Positive Advisory

The experiment is now as follows. Any intruder that is seen as arriving within plus or minus ALIM of the TCAS altitude at CPA will generate a positive advisory ("climb" or "descend"). If TCAS does not follow the advisory, there is some probability that the intruder will pass within 100 feet or less vertically at CPA. This probability depends upon ALIM and the magnitude of the altimetry errors (which are taken as Gaussian). ALIM is tabulated below.

Current ALIM Design

TCAS Altitude (ft)	ALIM (ft)
Sea Level - 10,000	340
10,000 - 18,000	440
18,000 - 29,000	640
Above 29,000	740

If TCAS does follow the advisory, there is a probability that the advisory will be in the wrong direction and the resulting vertical separation is again 100 feet or less. This second probability is a function of ALIM, the maneuver vertical displacement, D, and the magnitude of the altimetry errors. Since the proximity warning time, TAU, is a function of altitude, the maneuver displacement also varies with altitude. The current design, based on 5 seconds pilot delay, a maneuver acceleration from level flight of 8 feet per second squared, and a sustained vertical escape rate of 1500 fpm, is listed below.

Current Maneuver Vertical Displacement Design

TCAS Altitude (ft)	TAU	Displacement, D (ft)
Sea Level - 2,500	20	335
2,500 - 10,000	25	460
10,000 - 40,000	30	585
Above 40,000	35	710

It is assumed that TCAS has air carrier quality altimetry on board and intruders are equally likely to appear at all altitudes over plus or minus ALIM. The probabilities of close vertical proximity based on response and no response to the RA are shown on the slide as a function of the quality of altimetry equipment in the intruding aircraft.

At sea level, a positive advisory from a general aviation intruder indicates that, if neither aircraft maneuvers, the vertical proximity at CPA will be 100 feet or less 3 cases in 10. Following the RA reduces this risk by a factor of approximately 100. At 15,000 feet following the RA reduces this risk by a factor of 1000. For air carrier intruders, following the RA is even more effective. It reduces the risk of close vertical proximity at CPA by factors ranging from 100 to almost 1,000,000.

Probability of Wrong Way Advisory

The previous example of the effects of alimetry errors shows that on the average following the RA is vastly better than not following the RA. A second example is useful to ensure an understanding of the possible effects of altimetry errors. Here intruders are shown at various altitudes below TCAS. A wrong way advisory will occur if the combined altimetry errors in TCAS and the intruder cause the intruder to appear to be above TCAS. The probabilities of this outcome are tabulated on the slide.

Where intruders are below TCAS by an amount similar to the maneuver displacement, D, a wrong way advisory could result in close vertical proximity at CPA. For the example shown, the probabilities of wrong way advisories when TCAS and the intruder are initially separated by the maneuver displacement, D, range from 1 in 200 for a general aviation intruder to 1 in 10,000 for an air carrier intruder.

It should be recognized that the wrong way advisory is a reality in any separation assurance system that displays resolution advisories. Wrong way advisories resulting from altimetry errors are a factor in vertical resolution (whether the system be TCAS, BCAS, ACAS, or ATARS). Horizontal resolution is also susceptible to wrong way advisories though the associated surveillance error mechanisms are different. A resolution advisory means that traffic is nearby. From this alone, it is clear that a maneuver could either improve or degrade separation at a time when there may be little separation to spare. The RA indicates a direction to move to increase the <u>estimated</u> separation. The RA may be wrong, but the chances of this (associated with altimetry errors) are small, ranging between 1 in 100 and 1 in 1,000,000.

Observations on TCAS Resolution Advisories

Some conclusions can be reached with respect to resolution advisories:

(1) Their occurrence in the cockpit means that separation is predicted to be small (in some sense) in the immediate future. They do <u>not</u> mean that a collision is about to occur.

(2) They indicate a direction to move to increase estimated future separation. They are not infallible. Intruder maneuvers, surveillance errors, and equipment failures all degrade the separation assurance that can be provided.

(3) In certain cases, pilots will not follow resolution advisories. The pilot may have visual information that tells him response is unnecessary. Alternately, he may be in an environment where he is comfortable with the conventional separation service and concerned about encountering a second intruder, one with no transponder.

TCAS Program Directions

We propose to take advantage of what has been learned in structuring future TCAS program activities. In particular, we believe that a simple resolution advisory may be inadequate as information to be utilized in the air carrier cockpit for separation assurance. There is no means for interfacing such an advisory with conventional separation assurance information and the advisory, by itself, cannot be infallible. We believe that traffic advisory information is required both to link the resolution advisory to conventional information and to permit the crew to resolve encounters conventionally prior to the time the advisory is displayed. In addition, the traffic advisory tells the crew where to look to visually acquire the intruder as a means for confirming encounter resolution.

In the immediate future, we do not intend to follow resolution advisories in instrument meterological conditions (IMC) where three is no opportunity for the crew either to directly confirm resolution by visually tracking the intruder or to visually clear the airspace that TCAS is entering. Response to resolution advisories in IMC will be the subject of a comprehensive system safety analysis to be accomplished over the next six months.

Finally, in recognition of the fact that the TCAS crew may not follow the RA for any of several reasons, the maneuver intention message will be deleted from the crosslink to TCAS II. We will retain the traffic advisory. As before, this traffic advisory gives the position of TCAS II as seen by TCAS I and coveys the notion that the TCAS I crew should attempt visual acquisition while avoiding unnecessary abrupt maneuvers that could contradict a TCAS II avoidance maneuver.

TCAS Operational Use

While restraints will be applied to the use of TCAS during near term operational evaluation activities, the long term objective is to respond to TCAS resolution advisories under all weather conditions. It seems clear, nonetheless, that traffic advisories will continue to play a major role in the ways summarized here.

The FAA TCAS program plan is to evolve operational procedures over a period of time, starting with the baseline summarized on the previous vugraph, and extending to the long term objective stated above. This evolution will be based on system safety studies and experience gained in-flight.

ROLE OF TRAFFIC ADVISORIES IN TCAS II

O ALERT CREW TO USE CONVENTIONAL SEPARATION ASSURANCE TECHNIQUES:

- ATC
- SEE-AND-AVOID

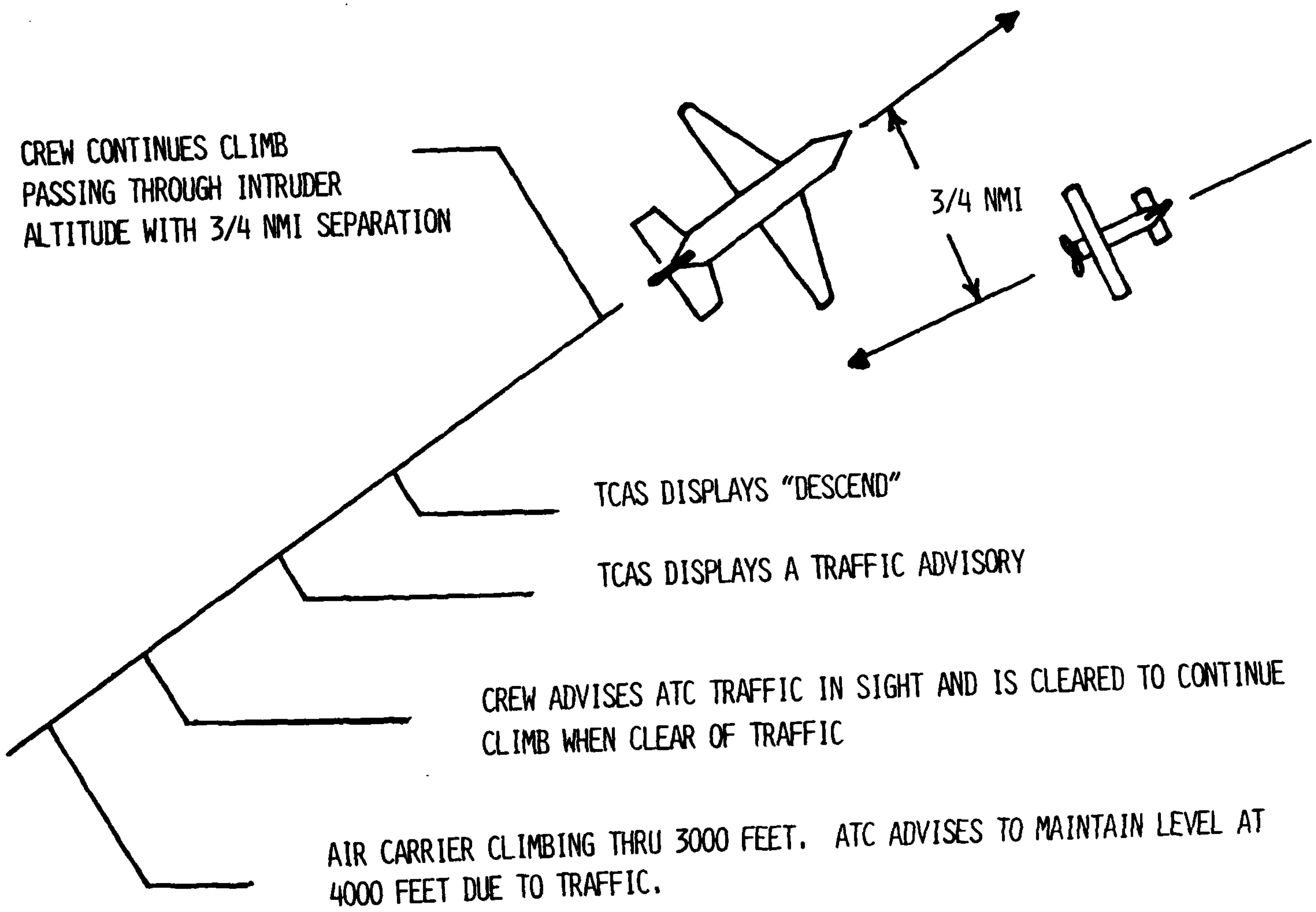
O CORRELATE RESOLUTION ADVISORIES WITH:

- TRAFFIC VISUALLY ACQUIRED
- TRAFFIC CALLED BY ATC

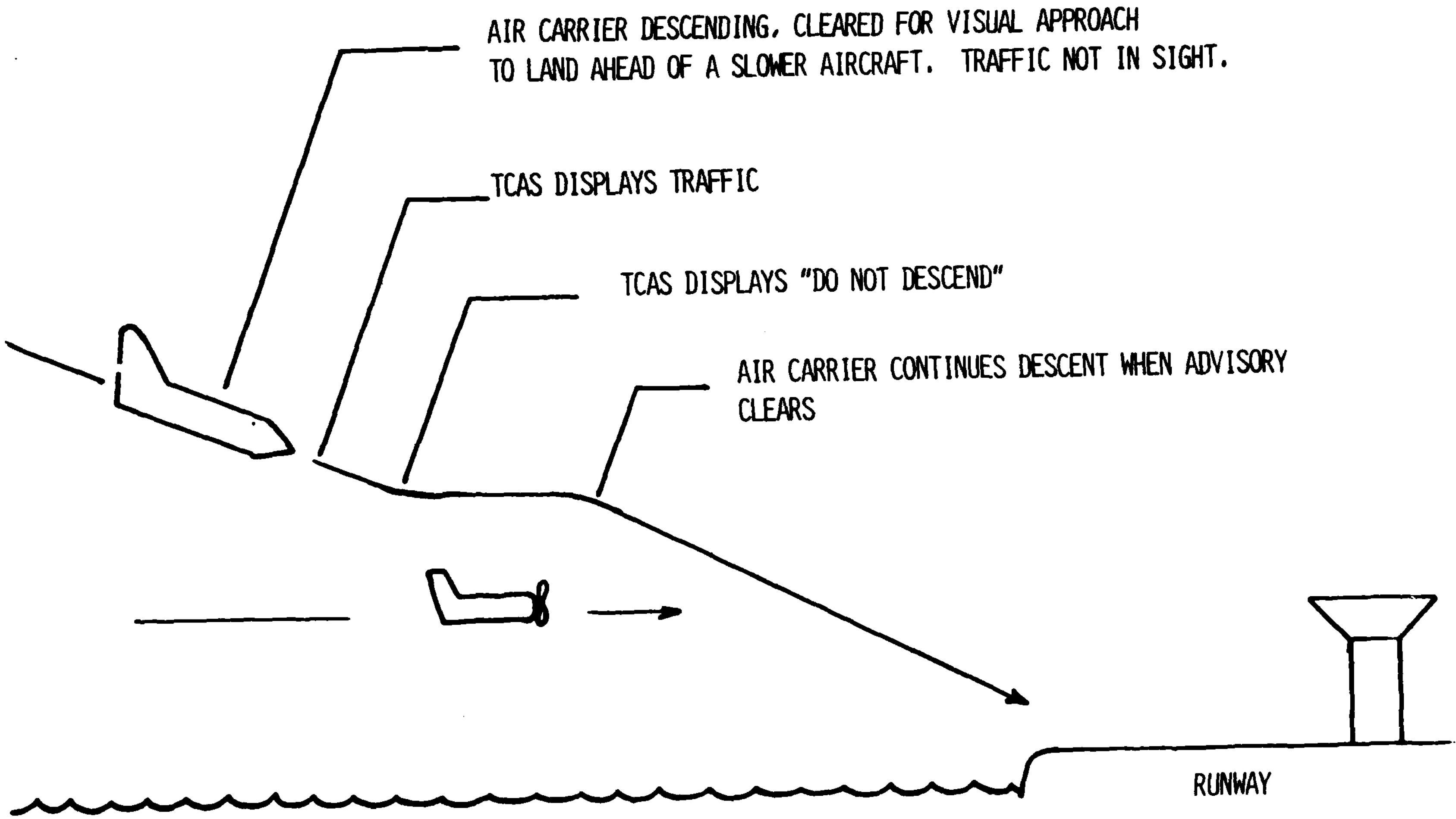
O CONFIRM RESOLUTION OF ENCOUNTERS:

- MANEUVERING INTRUDERS
- SURVEILLANCE ERRORS
- AVIONICS FAILURES

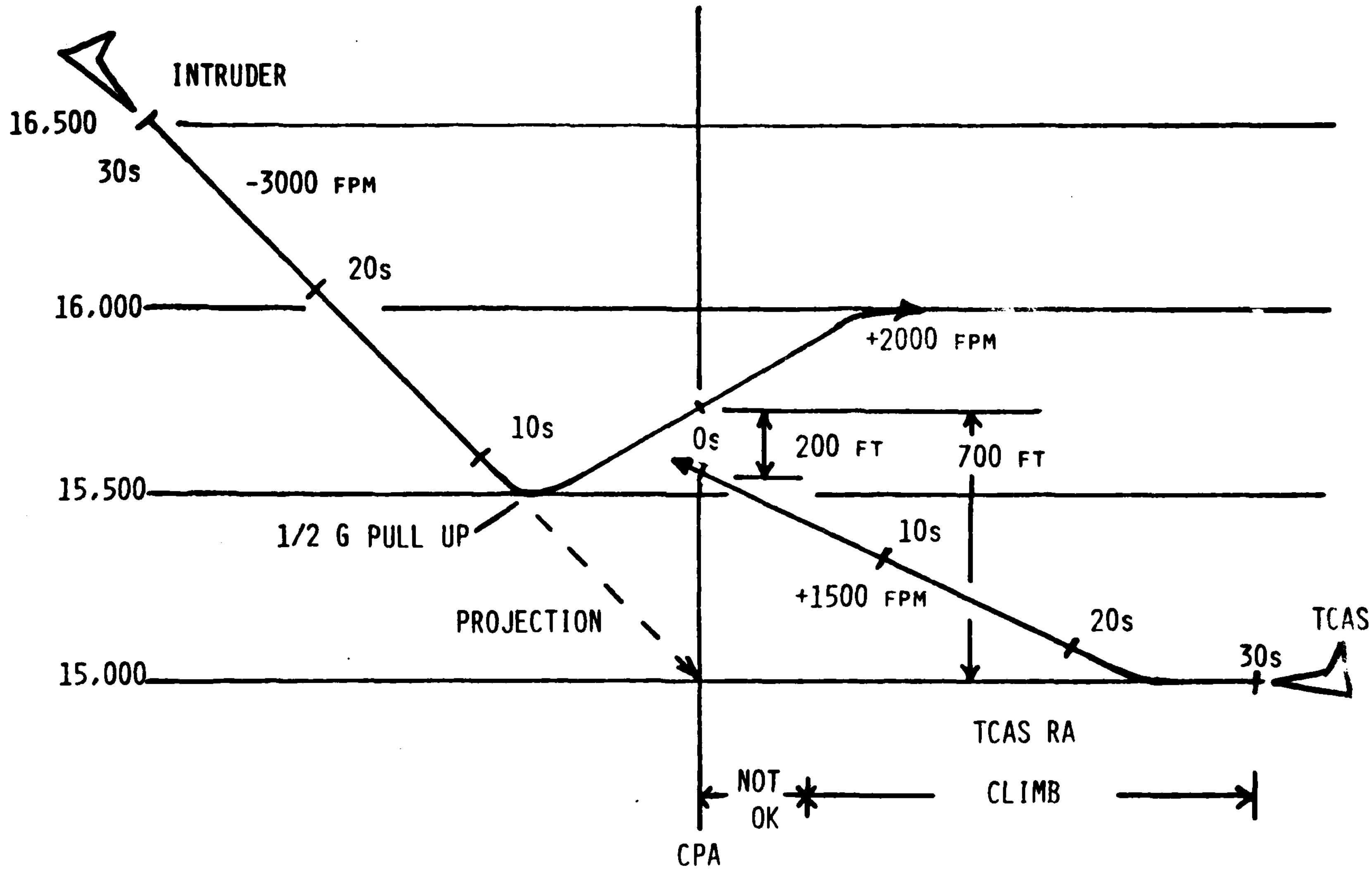
ALERT IN VISUAL CONDITIONS



ALERT ON FINAL APPROACH



ALERT DUE TO MANEUVERING INTRUDER



SIGNIFICANCE OF MINIMUM TCAS II ADVISORIES

O ALERT RATES IN AIR CARRIER ENVIRONMENT:

- TRAFFIC ADVISORIES ONCE PER 5 HOURS
- RESOLUTION ADVISORIES ONCE PER 37 HOURS

O ADVISORIES INDICATE TRAFFIC "NEARBY":

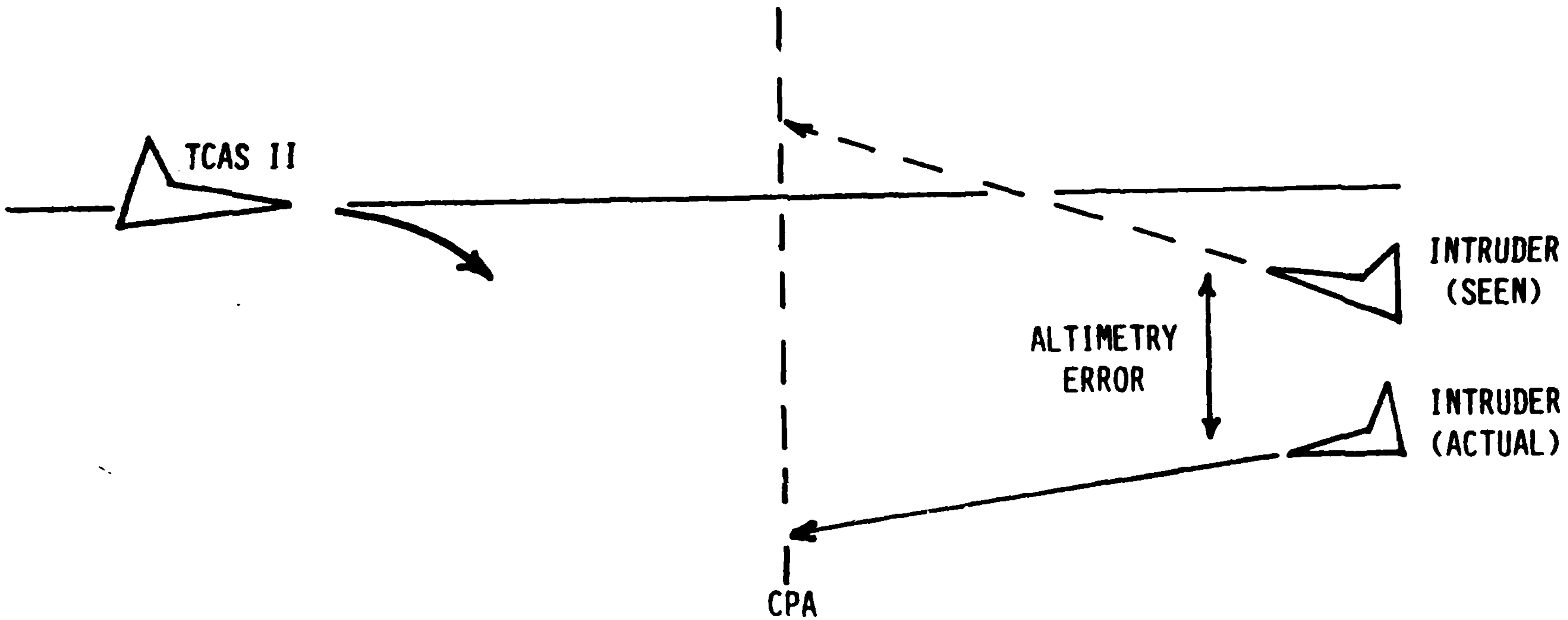
- TRAFFIC ADVISORY INDICATES POSITION OF PROXIMATE AIRCRAFT
- RESOLUTION ADVISORY INDICATES MANEUVER THAT SHOULD INCREASE SEPARATION

O PROBABILITY OF COLLISION, GIVEN A RESOLUTION ADVISORY, IS LESS THAN 1 IN 500,000.

DOCTRINE OPTIONS FOR RESPONSE TO RESOLUTION ADVISORIES

- FOLLOW THEM
- FOLLOW THEM UNLESS OTHER INFORMATION INDICATES RESPONSE UNNECESSARY OR INAPPROPRIATE
- IGNORE THEM UNDER CERTAIN CONDITIONS

RESPONSE VERSUS NO RESPONSE: ALTIMETRY ERRORS



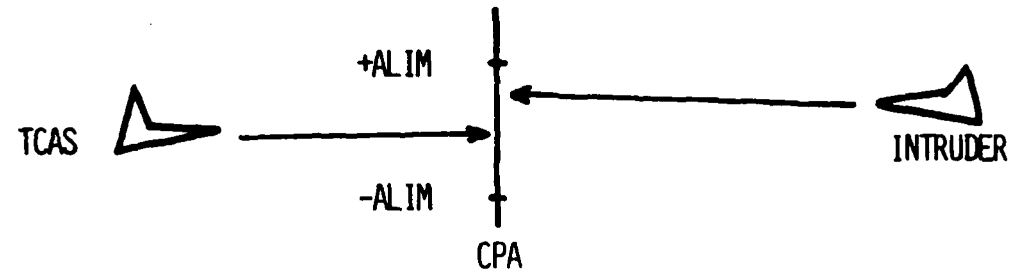
- INTRUDER PROJECTED TO BE ABOVE AT CPA
- TCAS II SELECTS "DESCEND"
- INTRUDER IS ACTUALLY BELOW

MAGNITUDES OF ALTIMETRY ERRORS

(ESTIMATED ERROR STANDARD DEVIATIONS, FEET)

ALTITUDE, FEET	AIR CARRIER	GENERAL AVIATION	IMPROVED GA
SEA LEVEL	51	104	60
5,000	54	118	66
10,000	57	131	75
15,000	63	146	83
20,000	68	160	92
25,000	73	175	100
30,000	80	190	109
35,000	86	206	119
40,000	92	220	127

RESPONSE VERSUS NO RESPONSE GIVEN POSITIVE ADVISORY

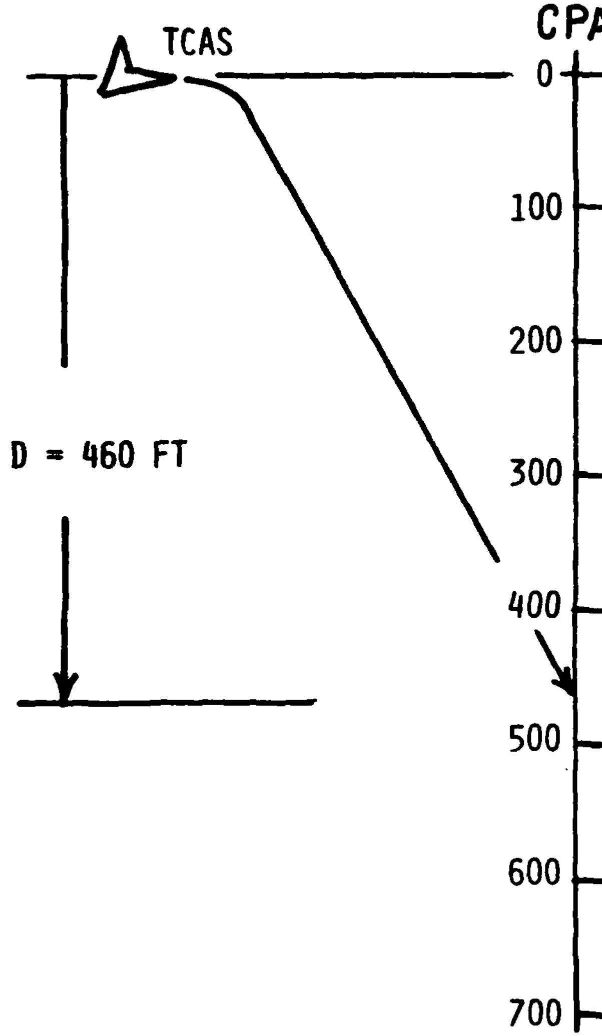


O PROBABILITY VERTICAL PROXIMITY AT CPA WILL BE 100 FEET OR LESS:

ENCOUNTER ALTITUDE, FEET	AIR CARRIER INTRUDER		GA INTRUDER	
	RESPOND	NO RESPONSE	RESPOND	NO RESPONSE
SEA LEVEL	$2X10^{-3}$	$3X10^{-1}$	$4X10^{-3}$	$3X10^{-1}$
5,000	$8X10^{-6}$	$3X10^{-1}$	$8X10^{-4}$	$3X10^{-1}$
15,000	$8X10^{-7}$	$2X10^{-1}$	$3X10^{-4}$	$2X10^{-1}$
30,000	$7X10^{-6}$	$1X10^{-1}$	$1X10^{-3}$	$1X10^{-1}$

PROBABILITY OF WRONG WAY ADVISORY

ENCOUNTER AT 9000 FT:



CPA	INTRUDER	AIR CARRIER	GA	IMPROVED GA
0				
100		.18	.26	.20
200		3.2×10^{-2}	.10	4.4×10^{-2}
300		2.7×10^{-3}	2.9×10^{-2}	5.2×10^{-3}
400		1.1×10^{-4}	5.7×10^{-3}	3.1×10^{-4}
500		1.8×10^{-6}	7.8×10^{-4}	9.6×10^{-6}
600		1.4×10^{-8}	7.3×10^{-5}	1.5×10^{-7}
700		4.6×10^{-11}	4.7×10^{-6}	1.1×10^{-9}

OBSERVATIONS ON TCAS RESOLUTION ADVISORIES

- O ADVISORIES DO NOT MEAN COLLISIONS ARE IMMINENT
- O ADVISORIES ARE NOT INFALLIBLE:
  - INTRUDER MANEUVERS
  - SURVEILLANCE ERRORS
  - EQUIPMENT FAILURES (TCAS AND MODE C)
- O IN CERTAIN CASES PILOTS MAY NOT FOLLOW:
  - VISUAL ACQUISITION OF INTRUDER
  - IMC BELOW 12,500 (POSSIBILITY OF THIRD AIRCRAFT WITHOUT TRANSPONDER OR MODE C)

TCAS PROGRAM DIRECTIONS

O CONTINUE OPERATIONAL EVALUATION WITH FOLLOWING DOCTRINE:

- USE TRAFFIC ADVISORIES TO RESOLVE ENCOUNTERS CONVENTIONALLY WHERE POSSIBLE
  * SEE-AND-AVOID
  * CONTACT ATC
- IN VMC FOLLOW RESOLUTION ADVISORIES (UNLESS UNNECESSARY) WHILE:
  * VISUALLY CLEARING AIRSPACE
  * IF POSSIBLE, VISUALLY CONFIRMING RESOLUTION
- IN IMC DO NOT FOLLOW RESOLUTION ADVISORIES:
  * MAY QUESTION ATC ABOUT DISPLAYED TRAFFIC

O INITIATE COMPREHENSIVE SYSTEM SAFETY STUDY:

- ASSESS SAFETY OF RESPONSE TO RESOLUTION ADVISORIES IN IMC

O CROSS-LINK TO TCAS I:

- RETAIN TRAFFIC ADVISORIES
- DELETE MANEUVER INTENTION ("ABOVE/BELOW")

TCAS OPERATIONAL USE (OBJECTIVE)

O USE TRAFFIC ADVISORIES TO RESOLVE ENCOUNTERS CONVENTIONALLY WHERE POSSIBLE

- SEE-AND-AVOID
- CONTACT ATC

O FOLLOW RESOLUTION ADVISORIES UNDER ALL CONDITIONS (UNLESS UNNECESSARY)

O IN VMC:

- VISUALLY CLEAR AIRSPACE
- IF POSSIBLE, VISUALLY CONFIRM RESOLUTION

Comparison of TCAS I

Passive and Active Transponder Detectors

Dr. Vincent A. Orlando

12 October 1982

Lincoln Laboratory

Massachusetts Institute of Technology

Lexington, Massachusetts 02173

Slide 1

TCAS I TRANSPONDER DETECTOR OVERVIEW

The purpose of this talk is to give the results of a study of the transponder detector function of the TCAS I.

The talk begins with a definition of the functions of TCAS I. This will be followed by a description of the passive and active transponder detector techniques studied, along with measured flight test performance for each. Results of a cost comparison of the passive and active detectors will be described along with an indication of the basis for the cost estimation.

The talk will conclude with a summary of the key points.

Slide 2

TCAS I FUNCTIONS AND COMPONENTS

There are three main characteristics of TCAS I.

1. TCAS I is able to respond with encoded altitude to interrogations from the air traffic control system on the ground and from airborne TCAS II units. Thus it includes a transponder and an encoding altimeter.

2. TCAS I has a means for displaying the traffic advisory received from TCAS II. This information is crosslinked from TCAS II to the transponder in the TCAS I aircraft. Thus, the transponder must be a Mode S transponder with an associated pilot display.

3. TCAS I has the capability of detecting transmissions from nearby transponders and alerting the pilot when the characteristics of any transmission indicate that it might be a threat.

Slide 3

TCAS I BLOCK DIAGRAM: PASSIVE DETECTOR

The Passive Detector TCAS I functions are shown in block diagram form on the slide. Note that:

1. The passive detector must work with both ATCRBS and Mode S transmissions.

2. Mode S aircraft will be detected by their squitter transmissions in regions where there is no ground interrogator, but ATCRBS aircraft will not be detected in these regions.

3. Some form of suppression is needed to integrate the passive detector with the TCAS I Mode S transponder since both operate on the same frequency.

Slide 4

SIMPLE PASSIVE FILTER CRITERIA STUDIED

The purpose of the passive filter is to cause pilot alerts only on transmissions received from potentially threatening aircraft, that is, aircraft that are close in both range and altitude. There are only a limited number of characteristics of a passively received reply that can be used as filter criteria. The most useful appear to be:

1. Received power level: The received power level compared to a fixed threshold can be used to reject transmissions from aircraft at long range. Power may also be tracked to determine how range is changing as a function of time.

2. Aircraft altitude: Transmissions from off-altitude aircraft may be rejected in two ways. First, by the inherent off-altitude rejection available through the aircraft antenna patterns. Second, by detecting the altitude code and comparing the received altitude to own altitude.

3. Time-after-interrogation: If an aircraft is close to and in the same ground interrogator beam as the TCAS I aircraft, its transmissions will be detected in the interval following the TCAS I transponder reply.

Of the techniques studied, received power level thresholding and altitude code filtering proved to be the most effective. These techniques were incorporated in a candidate passive detector used for in-flight performance measurements.

Slide 5

PASSIVE DETECTOR CHARACTERISTICS

A functional block diagram of the candidate TCAS I passive transponder detector is shown in the slide. A 1090 MHz receiver converts the RF transponder reply pulses into video pulses. These are passed to an amplitude comparator that is used to establish a detection threshold. This comparator can also be used to desensitize the detector each time the transponder on the TCAS I aircraft transmits so that the detector does not alarm on its own transponder replies. The detector should remain suppressed for an additional 40 microseconds to avoid triggering the detector on reflections from these replies.

Pulses that pass the detection threshold are then passed to ATCRBS and Mode S reply detectors that look for a valid pulse sequence and, if a valid sequence is detected, extract the altitude code from the reply. The altitude code is then compared to own aircraft's code. If the reply altitude is outside a ± 1500 foot altitude band or if it is an invalid altitude code, the reply is rejected. If the reply is in the band, or if the reply comes from a transponder that is not equipped with an encoding altimeter, the reply is accepted and an alarm is triggered if one Mode S reply or more than two ATCRBS replies are received in a two second interval.

The ALARM LOGIC controls the triggering and duration of the alarm. Once triggered, the alarm remains active for five seconds.

Slide 6

POWER THRESHOLDING ACQUISITION PERFORMANCE

In-flight measurements were made using the Airborne Measurement Facility to emulate the operation of the candidate passive detector. Once per second, active interrogations were generated to measure the range of nearby targets. A comparison of the passive and active data provided an indication of the performance of the power threshold filter.

The slide shows a histogram of initial acquisition range for the power threshold filter. As expected, the variation in received power across the population of nearby aircraft caused the acquisition range to vary from less than one to over 10 nautical miles. If the MTL were raised to eliminate the aircraft at long range, some aircraft at short range would not be detected.

Slide 7

PASSIVE DETECTOR ALERT RATE: ENROUTE AT 8500 FEET

The inability of the power threshold technique to reliably reject replies from long range aircraft can lead to high alert rates in moderately dense airspace.

Passive detector alert performance for a flight from Boston to Washington at 8500 feet is shown on the slide. Note the high percentage "ON" time over New York and on entry to Washington National Airport.

Slide 8

PASSIVE DETECTOR ALERT PERFORMANCE: ENROUTE AT 12,500 FEET

Alert rate performance for a second flight from Boston to Washington, at 12,500 feet, shows a somewhat lower alert rate over New York but about the same performance on entry to Washington National. The difference in alert rate performance may be partially attributed to the lower traffic density at the higher altitude.

Slide 9

TCAS I BLOCK DIAGRAM: ACTIVE DETECTOR

The performance limitations observed with the simple passive detector led to an investigation of a low power active transponder detector. The slide shows the block diagram of TCAS I with this type of detector. Note that:

1. The active detector transmits a standard ATCRBS Mode C interrogation and thus receives ATCRBS replies from ATCRBS and Mode S transponders.

2. Protection is provided against both ATCRBS and Mode S aircraft in regions where there is no ground interrogator.

3. Mutual suppression is required since both transponder and detector operate on both beacon frequencies.

Slide 10

ACTIVE TCAS I INTERFERENCE CONSIDERATIONS

An active detector approach is feasible only if a transmitted power that causes a negligible increase in signal interference also gives a useful detection range.

To answer this question, an analysis was conducted to determine the power level that could be employed by all aircraft in the highest predicted Los Angeles traffic density and that would cause no more than 10% of the signal interference generated by TCAS II operation. The result was a time-power product equivalent to one 2.5-watt Mode C interrogation every second (i.e., one 2.5-watt interrogation per second, one 5.0-watt interrogation every 2 seconds, etc.).

ECAC is currently conducting a detailed simulation to verify the accuracy of this analysis.

Slide 11

ACTIVE TCAS I TRACKING PROBABILITY

Calculated values of tracking probability for several peak powers are shown in the slide. The performance at 4 watts is also shown since in-flight data were available at that power level. Note that the calculated performance for a 10-watt Mode C interrogation (every 4 seconds) yields good detector performance out to 2 nautical miles.

The performance predection assumes no loss in detection due to synchronous garble and is therefore only applicable to densities where only one aircraft (on average) is within garble range. This single-aircraft density is shown for each of the ranges calculated.

The density of 0.024 aircraft/nmi^2 for a 2-mile range is equivalent to the current density outside of the TCA in the Boston and Washington areas.

Slide 12

VALIDATION OF CALCULATED ACTIVE TCAS I PERFORMANCE

A comparison of calculated and measured performance for the 4-watt case is shown on the slide. The airborne measurements are seen to be in good agreement with the calculated performance.

Slide 13

ACTIVE DETECTOR CHARACTERISTICS

A functional block diagram of a possible TCAS I active transponder detector is shown on the slide. A single 10-watt Mode C interrogation is generated once every four seconds. This standard ATCRBS interrogation (i.e., no P_4 pulse) elicits ATCRBS replies from both ATCRBS and Mode S aircraft. The interrogation is followed by a listening interval of approximately 70 μseconds, which is sufficient to receive replies from aircraft up to three nautical miles away. Received replies are tracked in order to eliminate fruit.

In addition to active surveillance, the detector shown also includes altitude code filtering. The alarm logic for the active detector can track range to derive range rate. This makes it possible to base alerts on the same Tau criterion used for the TCAS II, and should therefore lead to a very low false alarm rate.

Slide 14

ACTIVE TCAS I PERFORMANCE MEASUREMENTS

An example of the performance of a 4-watt active interrogator is shown on the slide. The lines represent the location of proximate aircraft as determined by an experimental TCAS II unit operating at full power. The dots indicate regions where the 4-watt interrogator elicited replies.

Slide 15

IMPLEMENTATION REQUIREMENTS

A second requirement for active TCAS I feasibility was that it did not appreciably increase the cost of the TCAS I equipped with a simple passive detector. This issue was addressed by comparing differences in the implementation requirements of the passive versus the active approach.

Every TCAS I, whether active or passive, incorporates a Mode S transponder (shown top center on the slide). For a TCAS I with a passive transponder detector, a second receiver and full-time logic must be added, as shown.

The use of an active transponder detector requires, in effect, another transponder complete with receiver, transmitter, and logic but operating on the opposite beacon frequencies. However, this "inverted" transponder is active for less than 100 μseconds every four seconds. It thus appears practical to time share the Mode S receiver and transmitter between the transponder and active detector tasks.

Details of the passive and active configurations are given in the following slides.

Slide 16

TCAS I PASSIVE TRANSPONDER DETECTOR

Individual building blocks for the transponder are shown in the upper half of the slide and their equivalents for the TCAS I passive detector are shown below. The double-bordered items are those that must be added to the TCAS I installation, either in a separate box or incorporated in the transponder enclosure. Some items may be less expensive than their equivalent in the transponder because the detector receiver needs about 20 dB less sensitivity than the transponder receiver.

Slide 17

TCAS I ACTIVE TRANSPONDER DETECTOR

This implementation of a TCAS I active transponder detector uses the existing transponder in a time-sharing mode. Switches effect the reconfiguration and frequency change. Note that there is no need for extreme speed or efficiency in the reconfiguration switches since: (1) time is available for switching, (2) insertion loss in RF energy switching is not critical since both sensitivity and RF power output are about 20 dB less, (3) Local Oscillator and Master Oscillator frequency switching can be done at the DC level, and (4) decoder switching is strictly a logic function.

Slide 18

PASSIVE VS ACTIVE DETECTOR RELATIVE COST

The items that must be added to a Mode S transponder to achieve a TCAS I passive or active detector capability are shown on the slide. A cost (in terms of the percentage of a Mode S transponder) is shown for each item along with the cost of the equivalent transponder item. The breakdown of Mode S transponder costs was derived from the ARINC-Research-FAA Cost Study, modified to include a solid state transmitter.

Only differences between the two approaches were counted in the costing. For example, data processing and display costs were not included since they were assumed to be the same for either approach. Thus the total for the passive detector additions is only significant in comparison to the value calculated for the active detector.

Slide 19

SUMMARY

Measurements indicate that the low power active approach provides more reliable detection of nearby aircraft and a lower alert rate than any of the simple passive techniques considered. The active approach also provides protection for both ATCRBS and Mode S aircraft in regions where there is no ground interrogator. In this environment the passive mode can detect Mode S aircraft only, through reception of the Mode S squitter transmissions.

This cost study indicates that the active TCAS I will cost approximately the same as a passive TCAS I. This result is due to the very low duty cycle of the active mode which makes it possible to time share the transponder transmitter and receiver elements. The passive mode cost is driven by the requirement for a separate receiver since both are required to listen full time: the transponder on 1030 MHz, and the detector on 1090 MHz.

SLIDE 1

TCAS I TRANSPONDER DETECTOR OVERVIEW

- TCAS I CONCEPT
- PASSIVE TCAS I } TECHNIQUES AND PERFORMANCE
- ACTIVE TCAS I }
- PASSIVE vs ACTIVE TCAS I COST COMPARISON
- SUMMARY

SLIDE 2

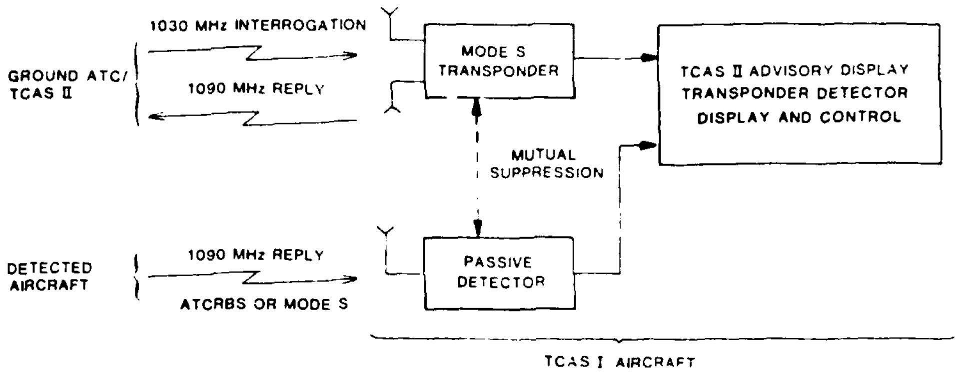
TCAS I FUNCTIONS AND COMPONENTS

- PROVIDES SURVEILLANCE ELEMENT FOR GROUND ATC AND TCAS II
  - TRANSPONDER
  - ENCODING ALTIMETER
- DISPLAYS TRAFFIC ADVISORY CROSSLINKED FROM TCAS II
  - TRANSPONDER MUST BE MODE S
  - TCAS II TRAFFIC ADVISORY DISPLAY
- DETECTS TRANSMISSIONS FROM NEARBY TRANSPONDERS
  - PASSIVE OR ACTIVE TRANSPONDER DETECTOR

SLIDE 3

TCAS I BLOCK DIAGRAM

PASSIVE DETECTOR



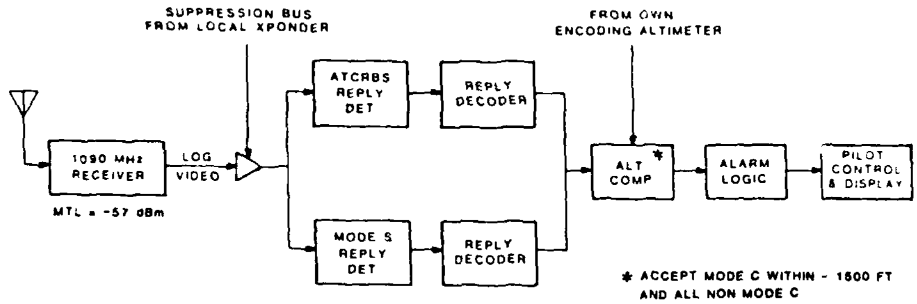
SLIDE 4

SIMPLE PASSIVE FILTER CRITERIA STUDIED

- RECEIVED POWER LEVEL
  - THRESHOLD
  - TRACKING
- ALTITUDE
  - ANTENNA PATTERN
  - ALTITUDE CODE
- TIME-AFTER-INTERROGATION

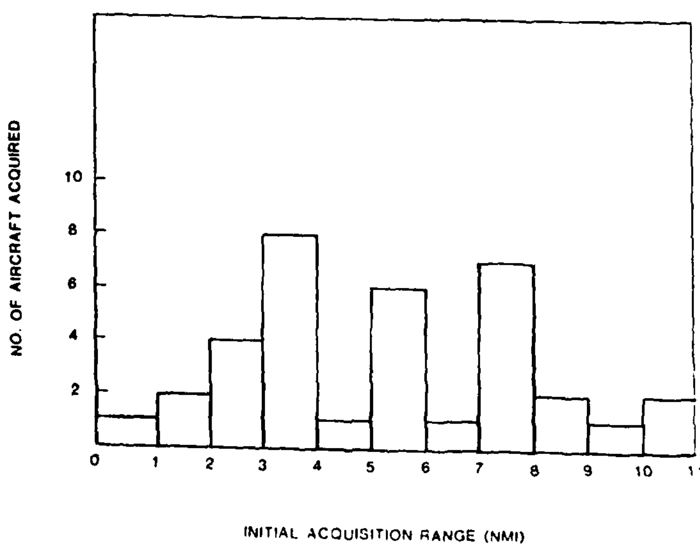
SLIDE 5

TCAS I PASSIVE TRANSPONDER DETECTOR FUNCTIONAL BLOCK DIAGRAM



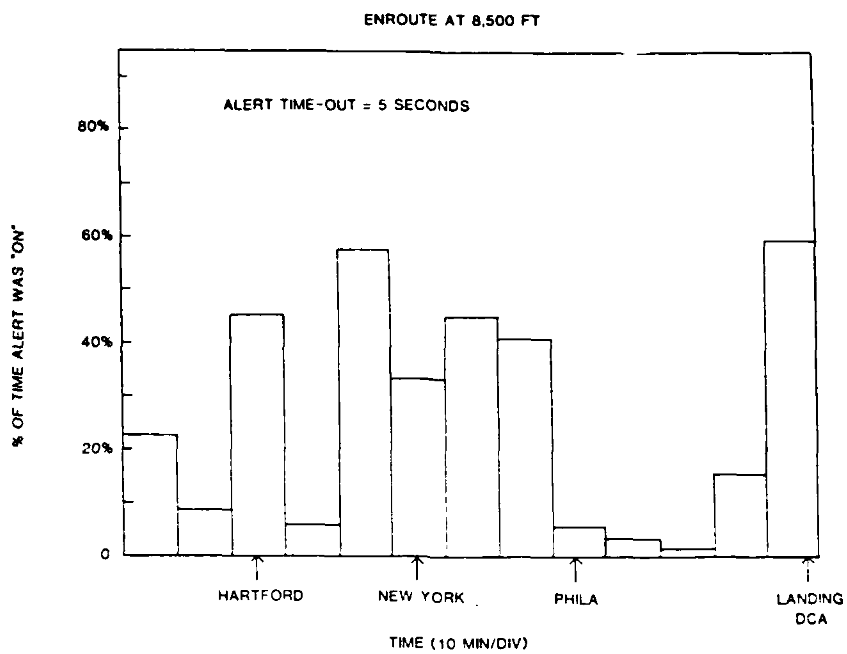
SLIDE 6

POWER THRESHOLDING ACQUISITION PERFORMANCE



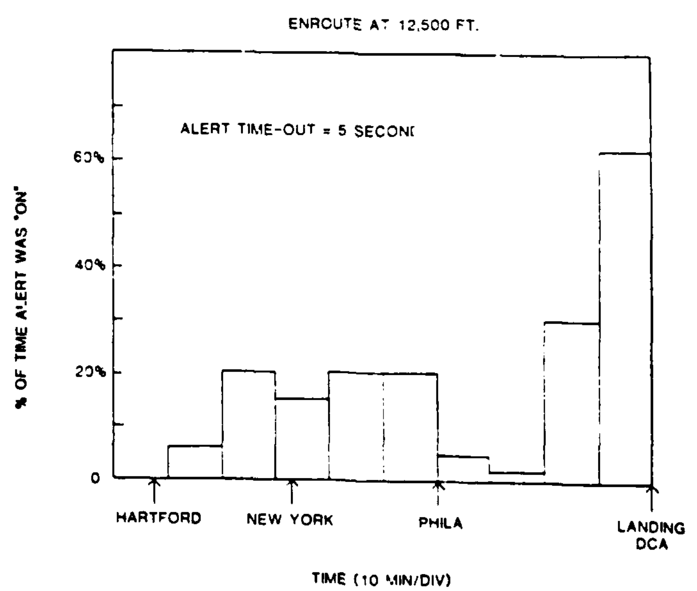
SLIDE 7

PASSIVE DETECTOR ALERT RATE: BOSTON TO WASHINGTON AT 8,500 FT



SLIDE 8

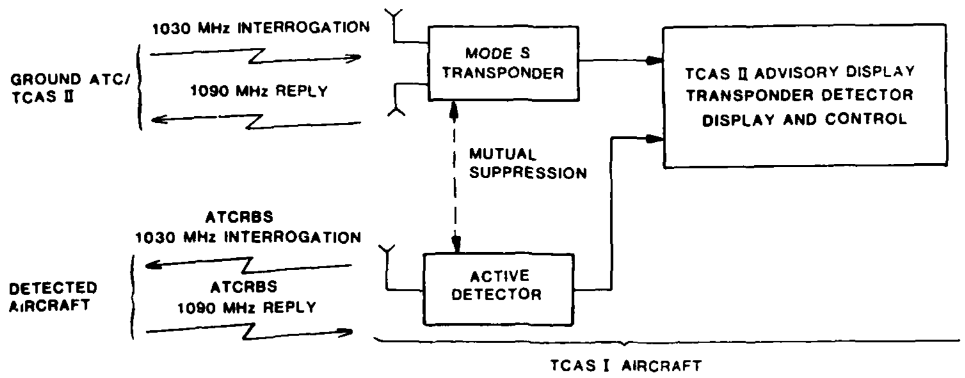
PASSIVE DETECTOR ALERT RATE: BOSTON TO WASHINGTON AT 12,500 FT



SLIDE 9

TCAS I BLOCK DIAGRAM

ACTIVE DETECTOR



SLIDE 10

ACTIVE TCAS I INTERFERENCE CONSIDERATIONS

CONSTRAINTS

- UNLIMITED IMPLEMENTATION IN ANY AIRSPACE
- NEGLIGIBLE INTERFERENCE TO GROUND AND TCAS II ENVIRONMENT

RESULTS

- TIME - POWER PRODUCT EQUAL TO ONE, 2.5 WATT MODE C INTERROGATION /SEC

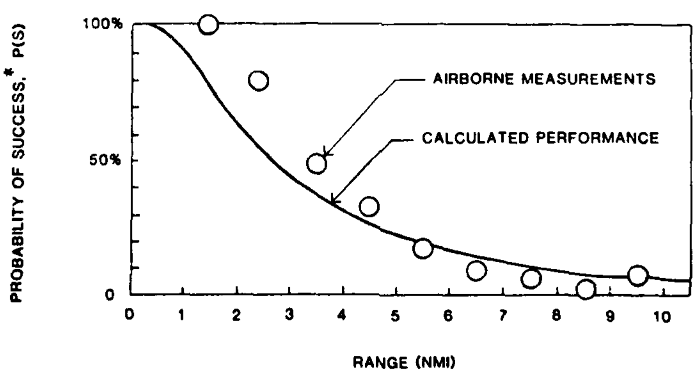
SLIDE 11

CALCULATED VALUES OF TRACKING PROBABILITY FOR A LOW POWER TCAS I DETECTOR

RANGE (NMI)	INTERROGATOR POWER (AT ANTENNA)				OPERATIONAL DENSITY
	2.5 WATTS	4 WATTS	5 WATTS	10 WATTS	AC/NMI^2
1	0.84	0.90	0.93	0.97	0.047
2	0.56	0.67	0.72	0.84	0.024
3	0.36	0.47	0.53	0.69	0.015
4	0.23	0.33	0.38	0.56	0.010

SLIDE 12

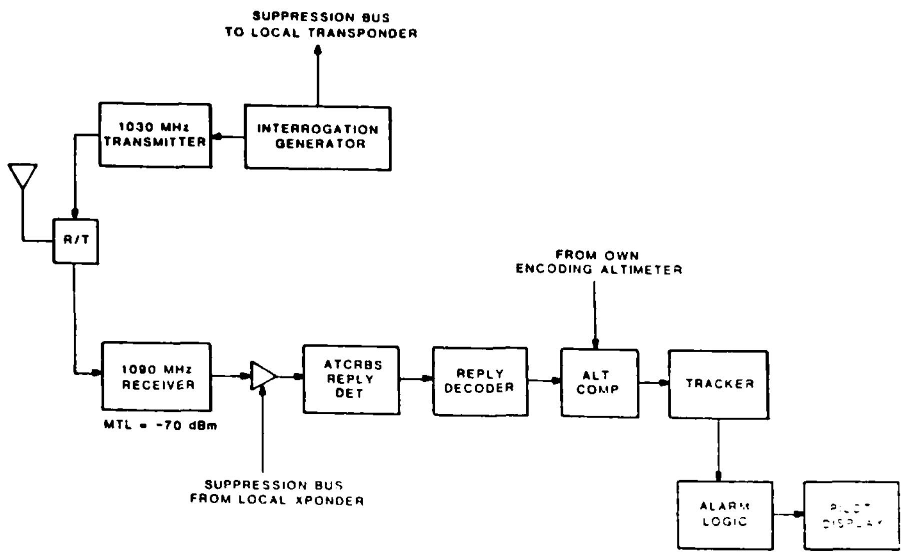
ACTIVE TCAS PERFORMANCE AS A FUNCTION OF RANGE



* PERCENT OF AIRCRAFT FROM WHICH REPLIES ARE ELICITED BY A 4-WATT INTERROGATION, FOR AIRCRAFT WITHIN ± 10° IN ELEVATION ANGLE

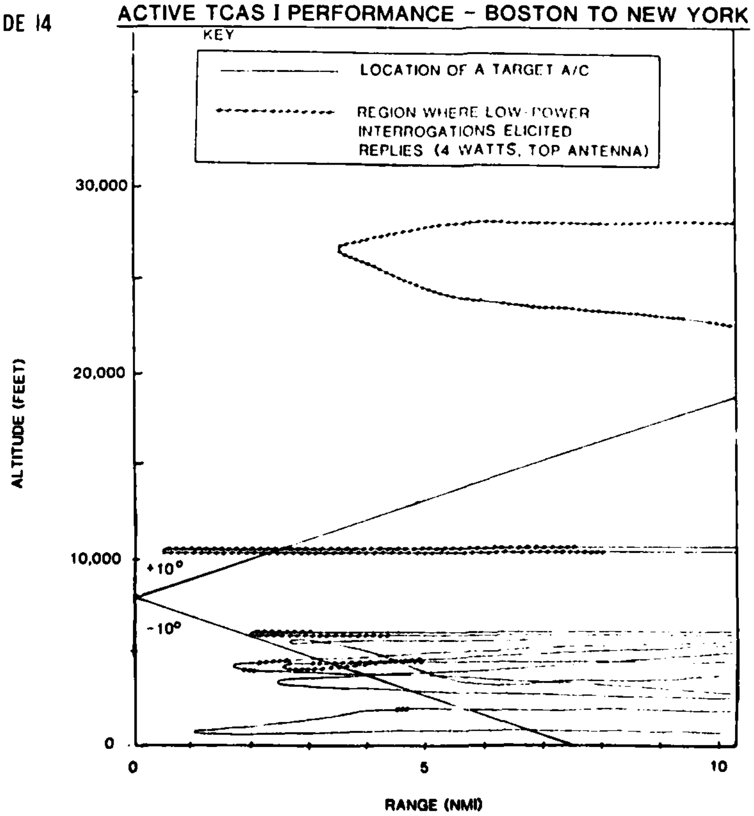
SLIDE 13

TCAS I ACTIVE DETECTOR FUNCTIONAL BLOCK DIAGRAM



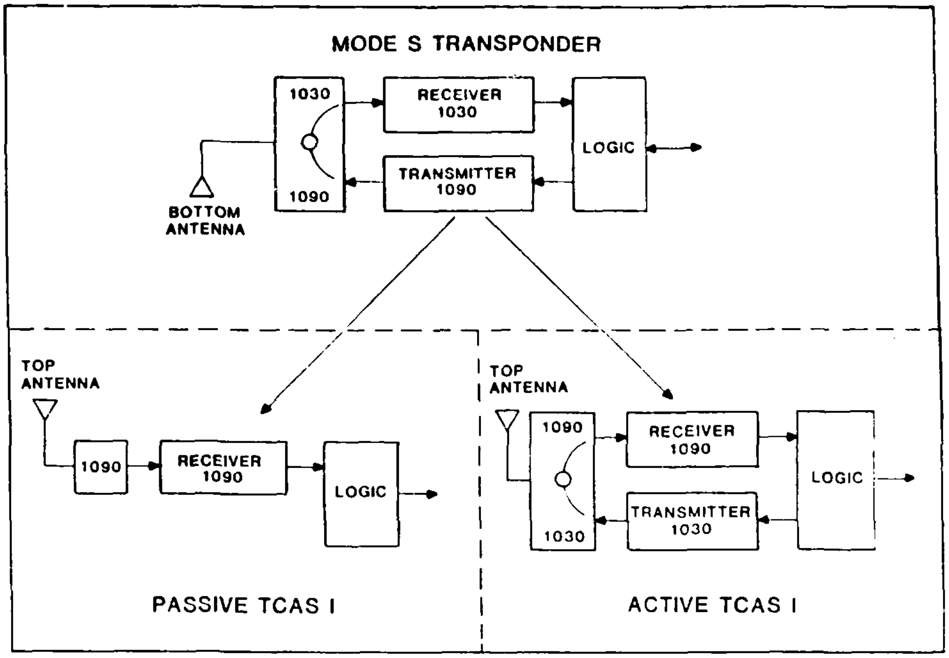
SLIDE 14

ACTIVE TCAS I PERFORMANCE - BOSTON TO NEW YORK



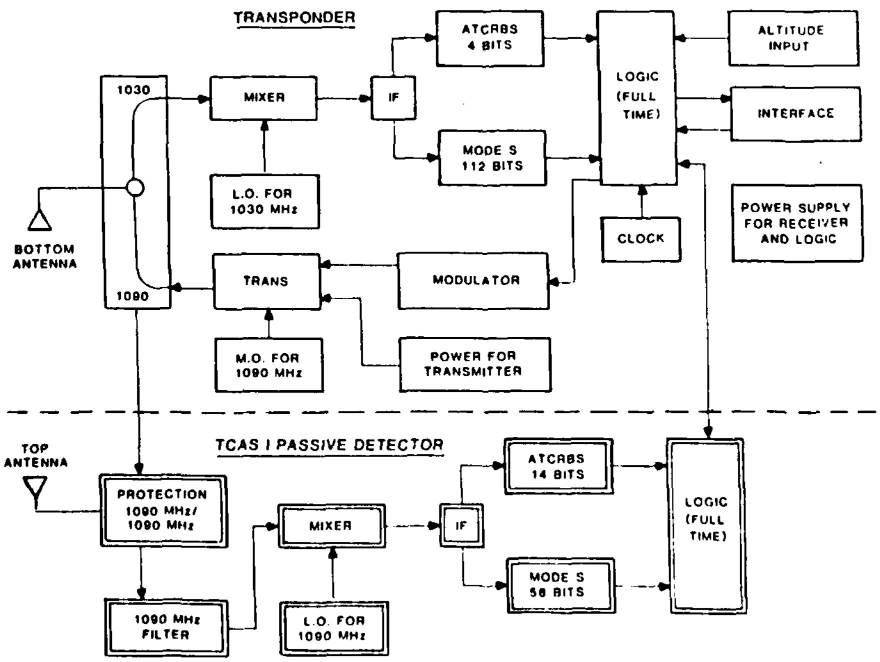
SLIDE 15

IMPLEMENTATION REQUIREMENTS



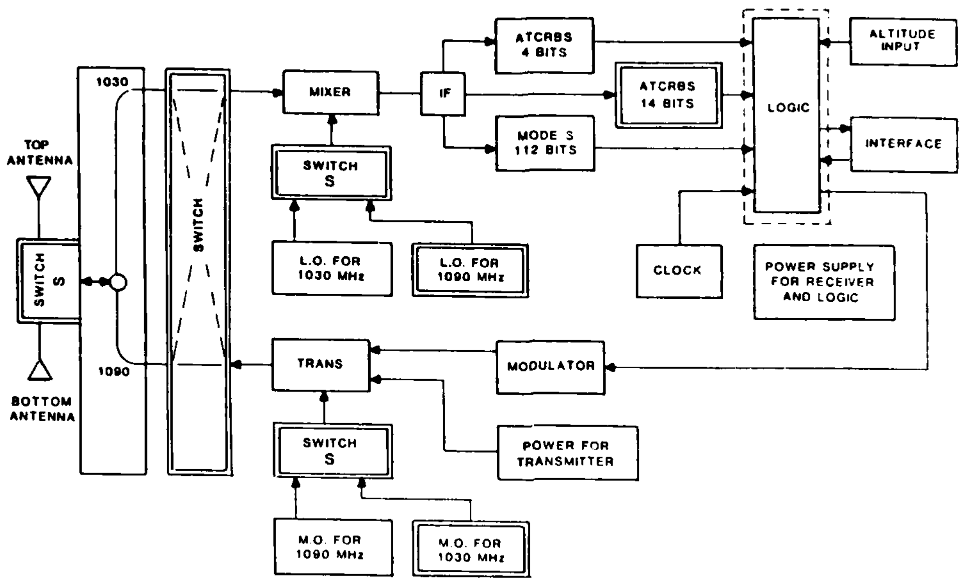
SLIDE 16

TCAS I PASSIVE TRANSPONDER DETECTOR IMPLEMENTATION DETAILS



SLIDE 17

TCAS I ACTIVE TRANSPONDER DETECTOR IMPLEMENTATION DETAILS



SLIDE 18

RELATIVE COST ESTIMATE - TCAS I PASSIVE vs ACTIVE DETECTOR

(IN PERCENTAGE OF MODE S TRANSPONDER COSTS)

ITEM	TRANSPONDER (%)	PASSIVE (%)	ACTIVE (%)
FRONT END	3	3	9
MASTER OSC	2.5	-	2.5
LOCAL OSC	2.5	2.5	2.5
RECEIVER IF	8.5	7	-
DEMODULATOR	3.5	3.0	2.0
POWER SUPPLY	5.5	1.0	1.0
MECHANICAL	12.0	2.0	1.0
		18.5%	[illegible]%

SLIDE 19

SUMMARY

ACTIVE vs PASSIVE TRANSPONDER DETECTOR

- PERFORMANCE

  MEASUREMENTS INDICATE THAT A LOW POWER ACTIVE TCAS 1 WILL PROVIDE BETTER PERFORMANCE THAN THE SIMPLE PASSIVE TECHNIQUES EVALUATED

- COST

  TIME SHARING TRANSPONDER TRANSMITTER AND RECEIVER ELEMENTS MAKES THE COST OF THE ACTIVE APPROACH EQUIVALENT TO THE PASSIVE APPROACH

MITRE

AIRCRAFT TRAFFIC IN THE LOS ANGELES BASIN AS RELATED TO TCAS REQUIREMENTS

12 OCTOBER 1982

N. A. SPENCER

B. P. COLLINS

- BACKGROUND
- NEW BASELINE
- PROJECTIONS

BACKGROUND

A number of high-stress traffic load models have been employed to assess performance characteristics of present and proposed systems. The basis for several such models was a survey, conducted in 1972, of the Los Angeles Basin. This survey was conducted by the FAA Technical Center and provided approximate flight profiles of a typical high activity period as compiled from a composite of several day's measurements. This was combined by The MITRE Corporation with growth data supplied by the FAA to produce several traffic models for various times and purposes.

Subsequent to this period, major factors - such as the oil embargoes - occurred which altered the extent of growth. In 1976, in support of the Mode-S developmental program, a relocatable sensor was moved to various locations around the country. In Los Angeles, this Transportable Measurement Facility provided an updated base of experience to apply to transponder-carrying aircraft.

Then in 1981 a new model was constructed using the same 1972 base, but correcting it for only the actual growth that had occurred since that time.

In the course of the TCAS program the need for a new baseline became apparent. That is the subject of this presentation.

BACKGROUND

- SURVEY IN 1972
  - CONDUCTED BY FAA TECHNICAL CENTER (25 AIRPORTS IN LA BASIN)
  - FAA PROJECTIONS FOR GROWTH
  - THREE MODELS
    - -- 1972 MODEL (495 AIRCRAFT)
    - -- 1982 MODEL (804 AIRCRAFT)
    - -- 1995 MODEL (1840 AIRCRAFT)

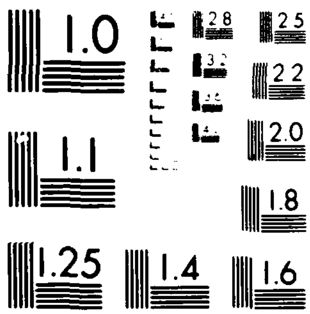
- TRANSPORTABLE MEASUREMENT FACILITY (TMF) IN 1976
  - 160 BEACON AIRCRAFT (UNKNOWN PRIMARY)

- LAX-1100 MODEL FOR 1995
  - SAME BASELINE: CURRENT FORECAST FOR 1981

AD-A123 037 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) SYMPOSIUM (3RD) OCTOBER 12-13 1982(U) FEDERAL AVIATION ADMINISTRATION WASHINGTON DC SYSTEMS RESEARC.. 1982

2/4

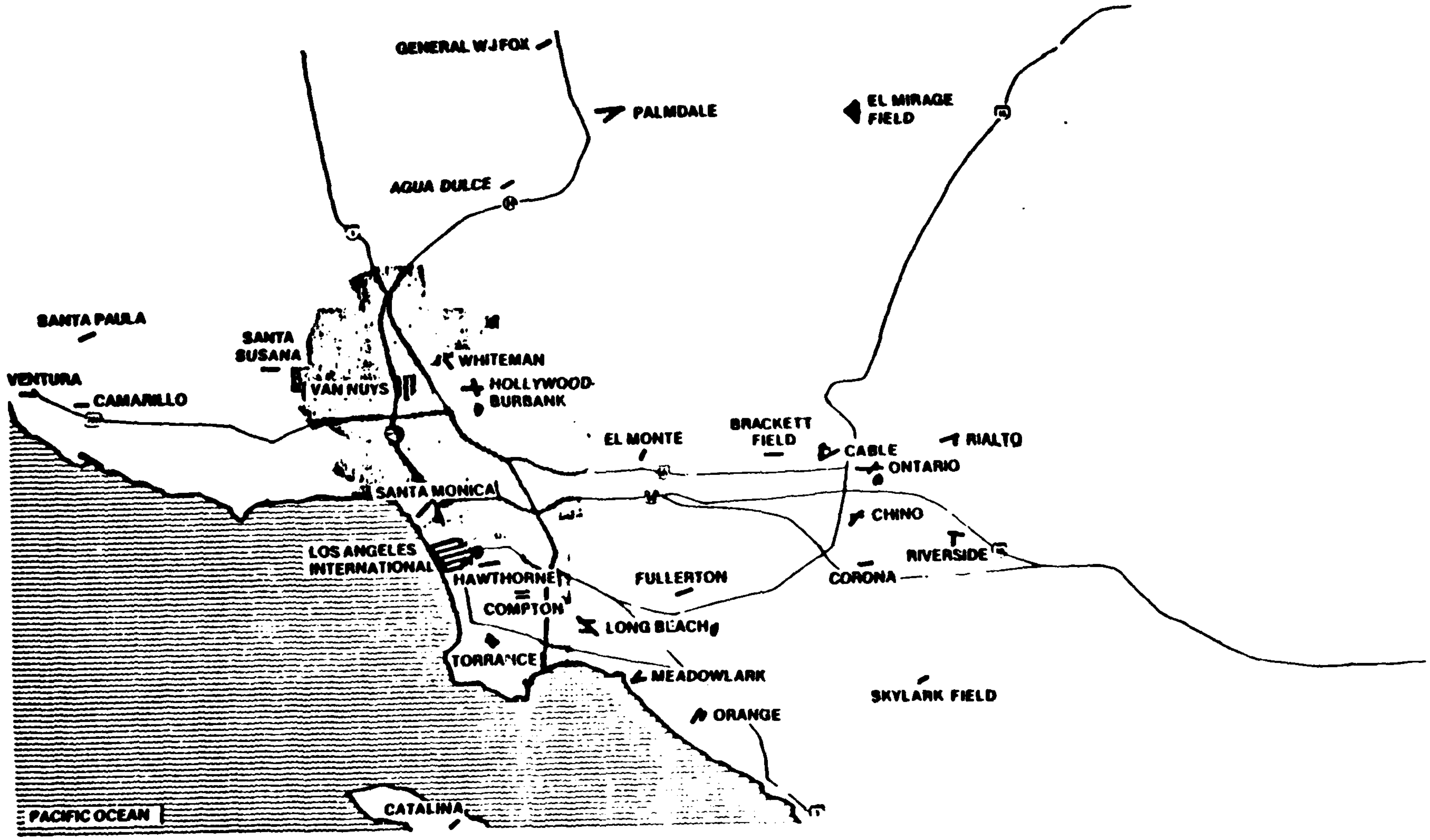
UNCLASSIFIED DOT/FAA/RD-82/75 F/G 17/7 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

REQUIREMENTS OF MODEL

- THE NEED FOR TCAS, AT THIS TIME, IS TO KNOW WHAT DENSITY OF AIRCRAFT TO EXPECT BY YEAR 2000.
- WILL PROVIDE INFORMATION FOR
  - TRACK FILE SIZE
  - GARBLE PROCESSING
  - IMPACT OF INTERFERENCE LIMITING FORMULAS ON TCAS

AIRPORT LOCATIONS



SOURCES OF DATA

- DATA WAS COLLECTED ON ALL BEACON AIRCRAFT FLYING IN THE LOS ANGELES BASIN BY USING AN AIRBORNE SSR.
- FAA WESTERN AND EASTERN REGIONS PROVIDED GROUND SSR DATA.
- FAA OFFICE OF AVIATION POLICY AND PLANS PROVIDED PAST RECORDS OF DAILY TOWER OPERATIONS. AS WELL AS FORECASTS OF YEARLY TOWER OPERATIONS FOR THE FUTURE.

FLIGHTS

Four different flights were conducted in the Los Angeles area to collect Airborne SSR data. The day of the week and the hour of the measurement were chosen to optimize the availability of resources and the predicted high traffic activity time. The weather in general was good, only one day having periods of light showers. A few flights were made in the vicinity of New York. These confirmed that Los Angeles indeed had more dense traffic, but was not by any means a freakish condition.

FLIGHTS

LOS ANGELES

15 DECEMBER 1981
TUESDAY, 1100 LOCAL TIME
5 MILE VISIBILITY

11 MARCH 1982
THURSDAY, 1600 LOCAL TIME
LIGHT RAIN
7 MILE VISIBILITY

3 JUNE 1982
THURSDAY, 1400 LOCAL TIME
10 MILE VISIBILITY

23 JULY 1982
FRIDAY, 1400 LOCAL TIME
12 MILE VISIBILITY

NEW YORK

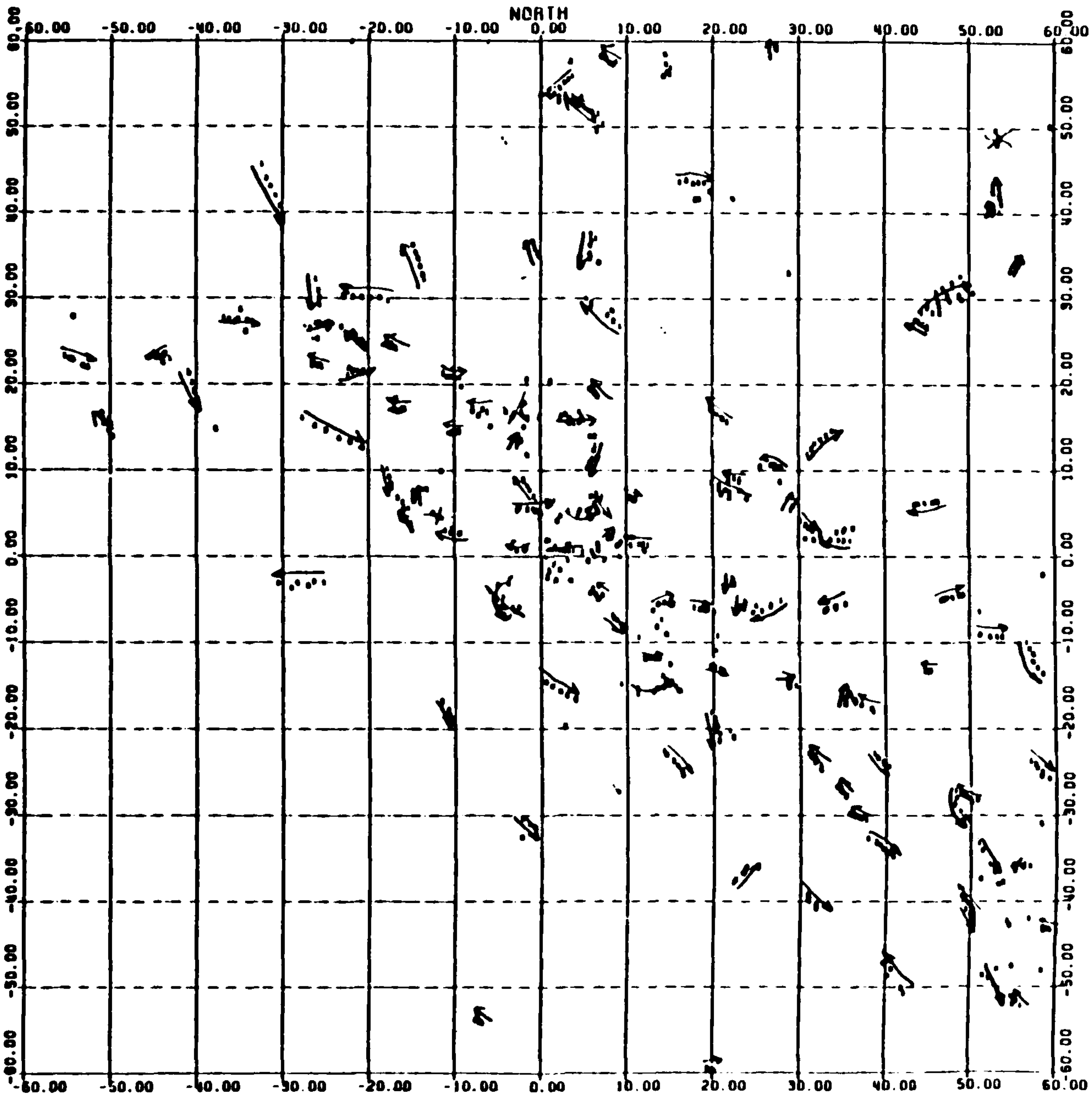
9 JULY 1982
FRIDAY, 1300 LOCAL TIME
10 MILE VISIBILITY

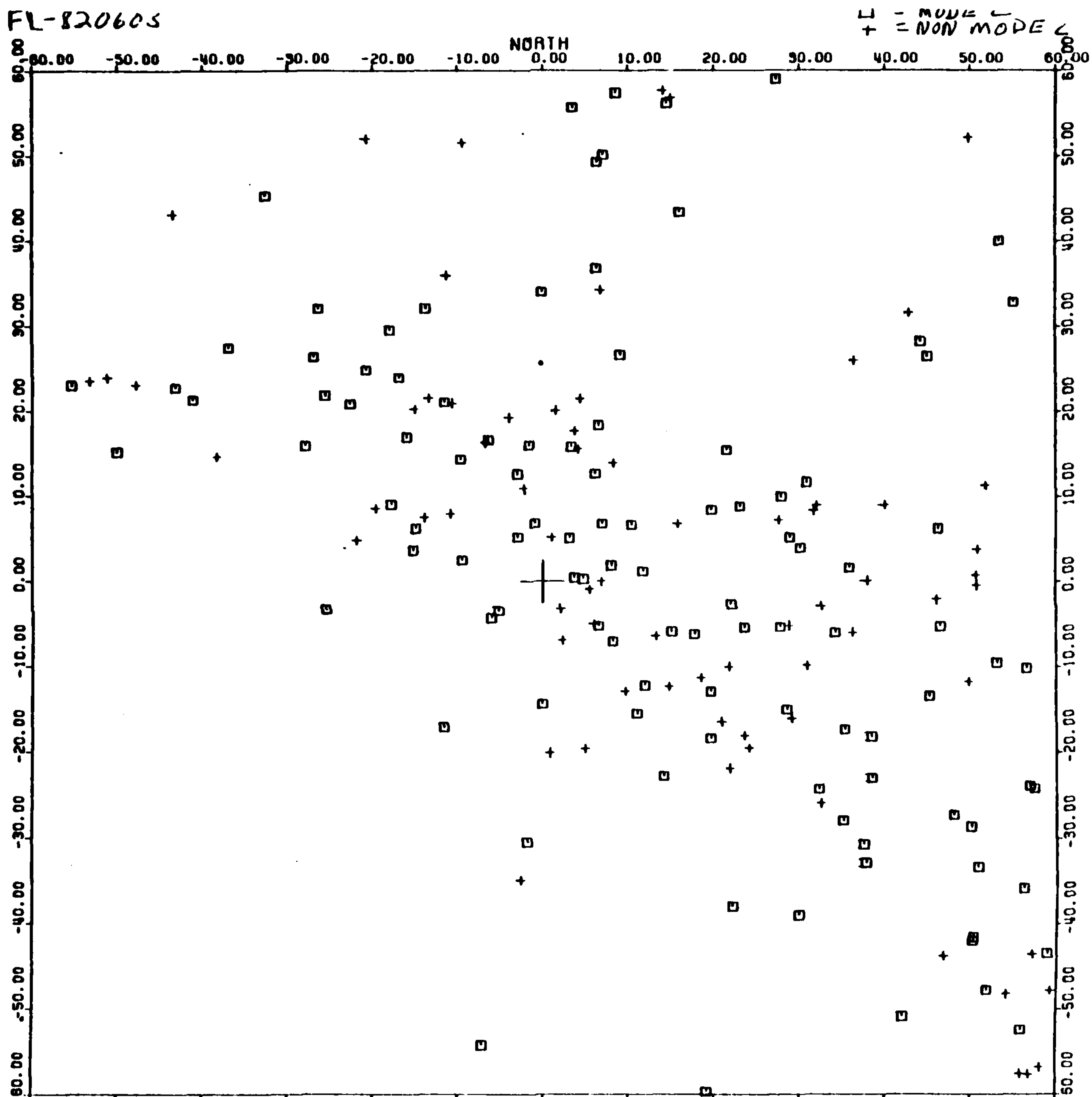
PROCESSING OF AIRBORNE SSR DATA

- DATA CONSISTED OF A CONTINUOUS STREAM OF TARGET REPORTS. TYPICALLY FROM 1/2 TO 1 HOUR DURATION.
- REMOVED ALL REPORTS OUTSIDE THE LOS ANGELES BASIN. A SQUARE REGION CENTERED ON LAX AND EXTENDING 60 NMI IN EACH DIRECTION.
- BREAK REPORTS INTO SCANS.
- FIND THE TIME WHEN THE NUMBER OF BEACON REPORTS ARE BOTH HIGH AND CONSISTENT.
- PLOT A STRING OF SEVERAL SEQUENTIAL SCANS AND CORRELATE VISUALLY.
- KEEP A SINGLE SSR TARGET REPORT FOR EACH CORRELATABLE STRING.

FC-8206·3 7/4745

MODE C




FL-820605
□ = MODE C
+ = NON MODE C
NORTH

0	0	0	0	0	2	0	0	0	0	2	1	0	0	0	0	1	0	0	0	0	1	0
0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0
1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	0	0	1	0	0	2	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1	0
1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0
0	0	0	0	0	0	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	1	1	0	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	0	1	1	3	0	0	0	0
0	0	0	0	0	0	0	0	0	0	2	0	0	1	2	0	0	0	1	1	1	0	0
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0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	3	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
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0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	2

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AIRCRAFT IN HEAVILY OCCUPIED CELLS

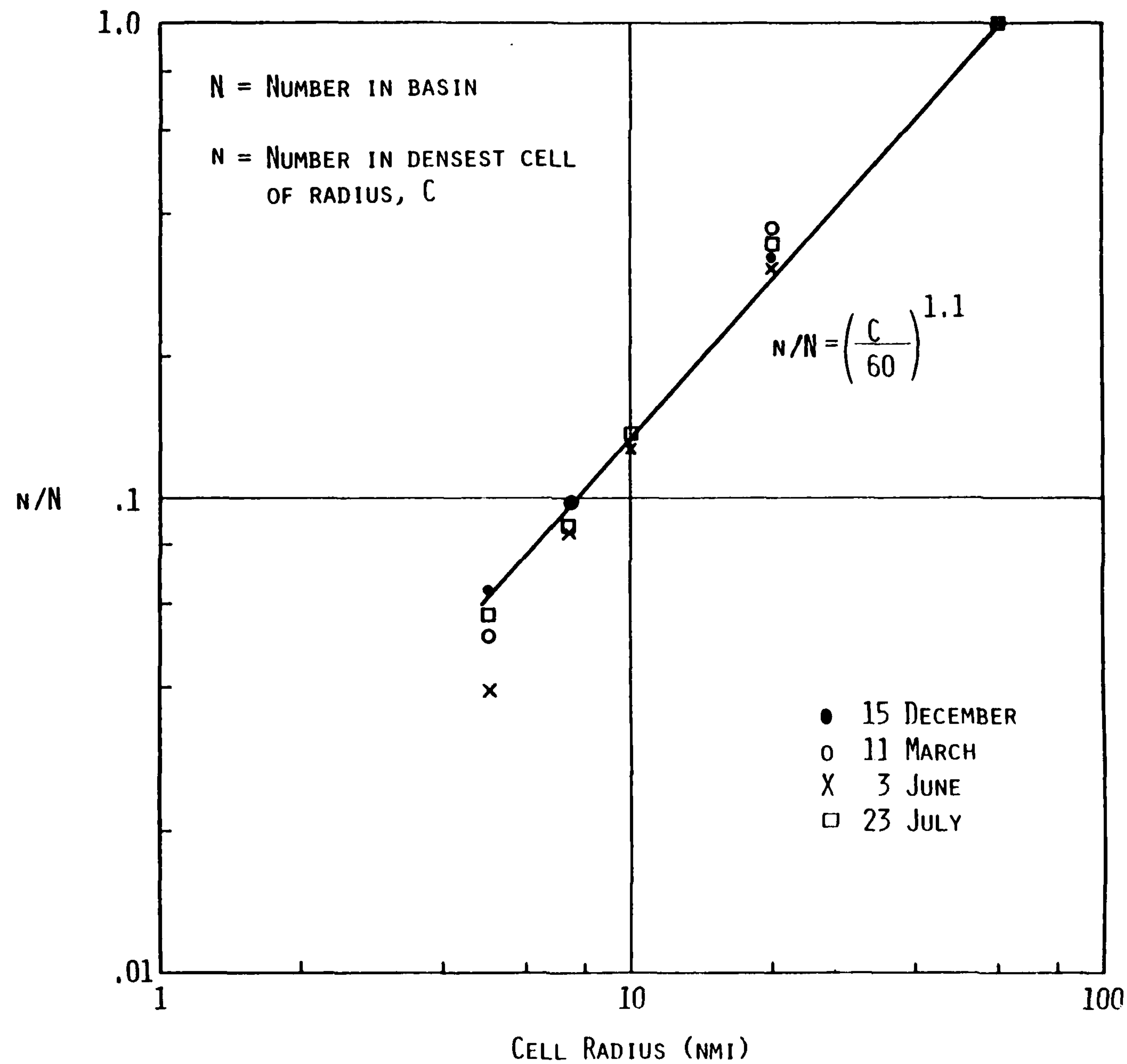
After the aircraft positional data was divided into small increments in the X, Y plane, it was found that all four flights had a very simple and similar characteristic; namely that the highest density encountered was a simple power relation (nearly linear) to the size of the cell under investigation. Thus the airborne data aggregated over the entire Los Angeles Basin (cell radius = 60 nmi), could be used to predict the number of aircraft within the region of interest -- typically a cell radius of 10 nmi or of 5 nmi (depending on the phenomenon being studied).

The relation applies very well down to a cell radius of 10 nmi, and with fair but conservative precision to a radius of 5 nmi.

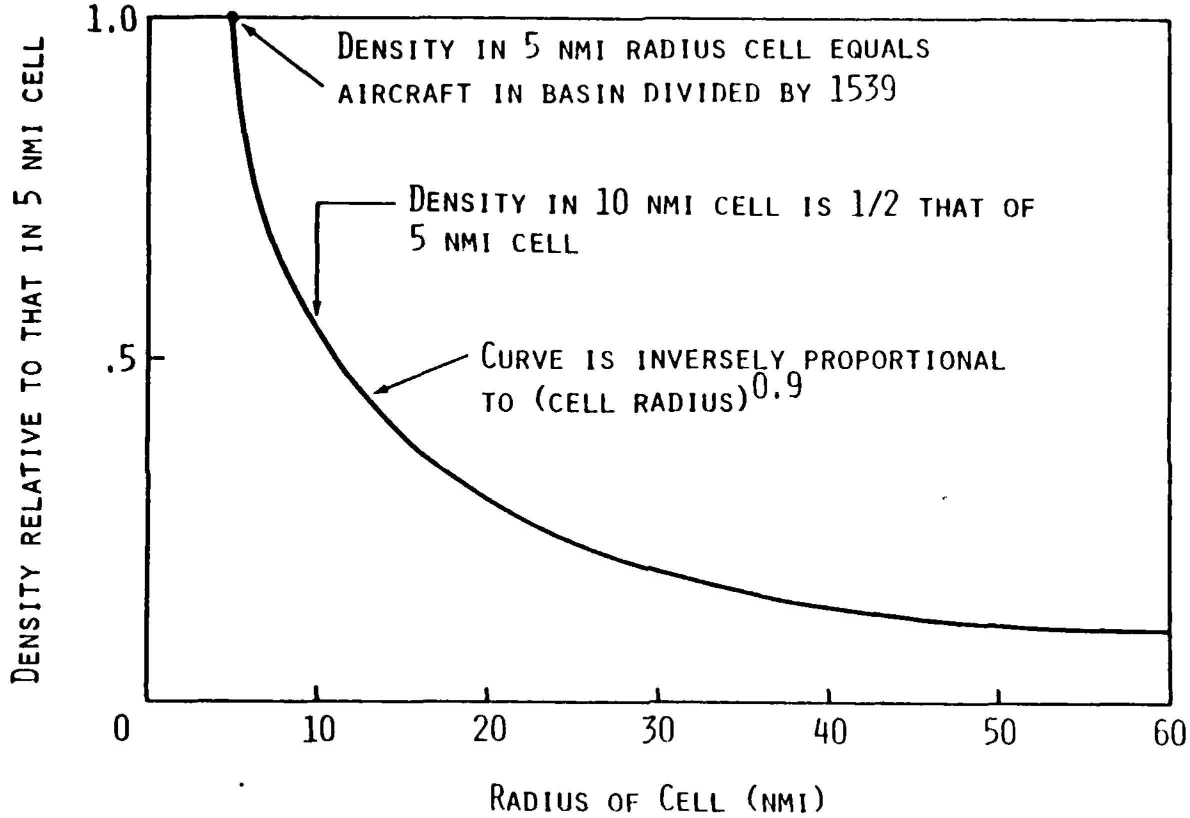
Converting the relation to determining the maximum density, one obtains the experimental numerical relation that the density of a cell of radius 5 nmi is (1/1539) times the number of aircraft in the basin. Furthermore, this density falls off very nearly linearly with cell radius.

AIRCRAFT IN HEAVILY OCCUPIED CELLS

- ALL FOUR FLIGHTS WERE FOUND TO BE ADEQUATELY CHARACTERIZED BY THE SAME SIMPLE RELATION BETWEEN:
  - THE RADIUS OF THE CELL
  - THE MAXIMUM NUMBER OF AIRCRAFT IN A CELL
  - THE INSTANTANEOUS AIRBORNE COUNT (IAC) IN THE BASIN
- ONE FORMULA AVERAGES ALL VARIATIONS NORMALLY FOUND OVER:
  - TIME
  - LOCALITY
  - OPERATIONAL CONDITIONS
- INTERPRETING THE FORMULA IN TERMS OF DENSITY RELATIVE TO THAT IN A 5 NMI CELL. ONE SEES A NEARLY ONE-OVER-RADIUS RELATION.
  - THIS IS IN ACCORD WITH OBSERVATIONS IN 1978 BY MIT LINCOLN LABORATORY WITH THE TMF
  - IT PERMITS US TO RELATE IAC TO DENSITY FOR TCAS NEEDS


1.0
.1
.01
1
10
100
N/N
N = Number in basin
N = Number in densest cell
of radius, C
N/N = (C/60)^1.1
15 December
11 March
3 June
23 July
Cell Radius (nmi)

VARIATION OF DENSITY WITH CELL RADIUS



ESTIMATE OF NON TRANSPONDER TARGETS

- THE FOREGOING RELATED ONLY TO BEACON TARGETS, BOTH MODE C AND NON MODE C.
- TO GET AN ESTIMATE OF THE NUMBER OF AIRCRAFT FLYING WITHOUT TRANSPONDERS IN THESE DENSE AREAS, A SPECIAL REQUEST WAS MADE TO THE WESTERN REGION TO OBTAIN RECORDINGS OF THE COMMON DIGITIZER FROM THE SAN PEDRO LONG RANGE RADAR NEAR LAX.
- THE CD DATA WAS TAKEN ON 23 JULY 1982, SOME 2 HOURS BEFORE THE FLIGHT DATA, BUT BOTH WERE AROUND THE EXPECTED MID-DAY PEAK.
- CLUTTER IS THE MOST OBVIOUS FEATURE OF THE RADAR RETURNS, BUT BY EXPANDING AND CAREFULLY EXAMINING THE SCAN-BY-SCAN DATA, A GOOD ESTIMATE OF THE NUMBER OF TARGETS WITHOUT TRANSPONDERS CAN BE MADE.
- FOR THE SAN PEDRO RADAR IN THE HIGH DENSITY REGION OF LOS ANGELES, IT WAS FOUND THAT THE TOTAL NUMBER OF AIRCRAFT IS 1.18 TIMES THE NUMBER OF BEACON AIRCRAFT.

ACCOUNTING FOR TRAFFIC VARIATIONS

- HOURLY
- DAILY
- YEARLY

HOURLY VARIATIONS

- FLIGHTS WERE SCHEDULED TO TAKE DATA AT PEAK TIME DURING EACH DAY.
- THE HOURLY OPERATIONS DATA THAT WE WERE ABLE TO OBTAIN SHOWED THAT THE FLIGHTS WERE INDEED CONDUCTED NEAR PEAK ACTIVITY TIMES.
- NO SPECIFIC ADJUSTMENT WILL BE MADE FOR HOURLY VARIATIONS.

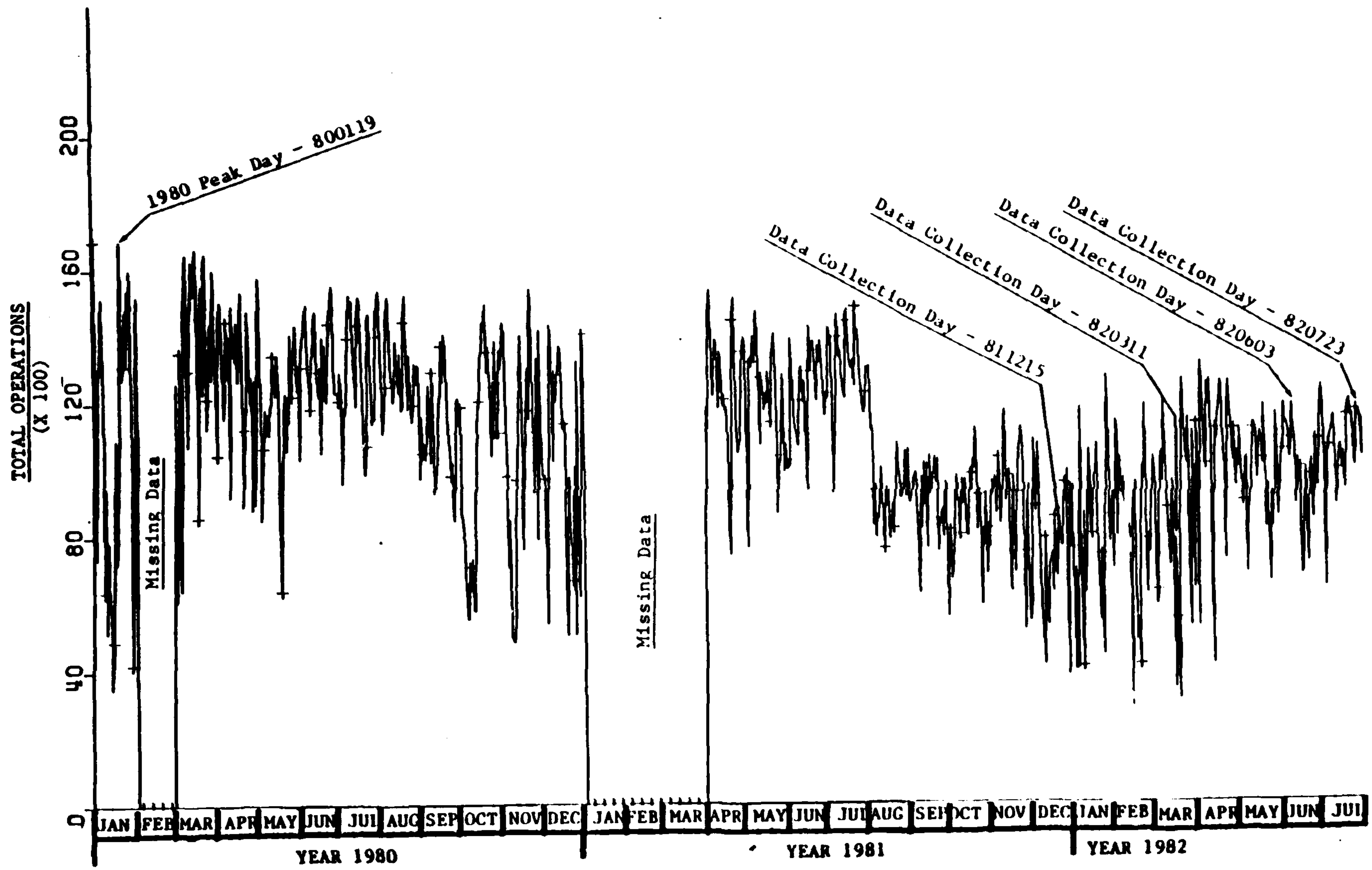
DAILY VARIATIONS

- OBTAIN OPERATIONS AT ALL TOWERS IN LOS ANGELES BASIN
- USE MEASURED DATA TO DETERMINE HOW TO MAKE THE ADJUSTMENT

LOS ANGELES BASIN TOWERS DAILY OPERATIONS

Data providing a record of the sum of all operations at all 17 towers in the Los Angeles Basin was supplied by the FAA. The sudden drop observed in August 1981 was caused by the controller strike. The activity on the two earlier days of data collection was relatively low, while for the two later days the activity had increased substantially. The peak activity to be used for normalization is chosen to be the highest activity in 1980, the year preceding the strike. This is seen to be a peak, but one which is only moderately higher than several other instances.

LOS ANGELES BASIN TOWERS DAILY OPERATIONS

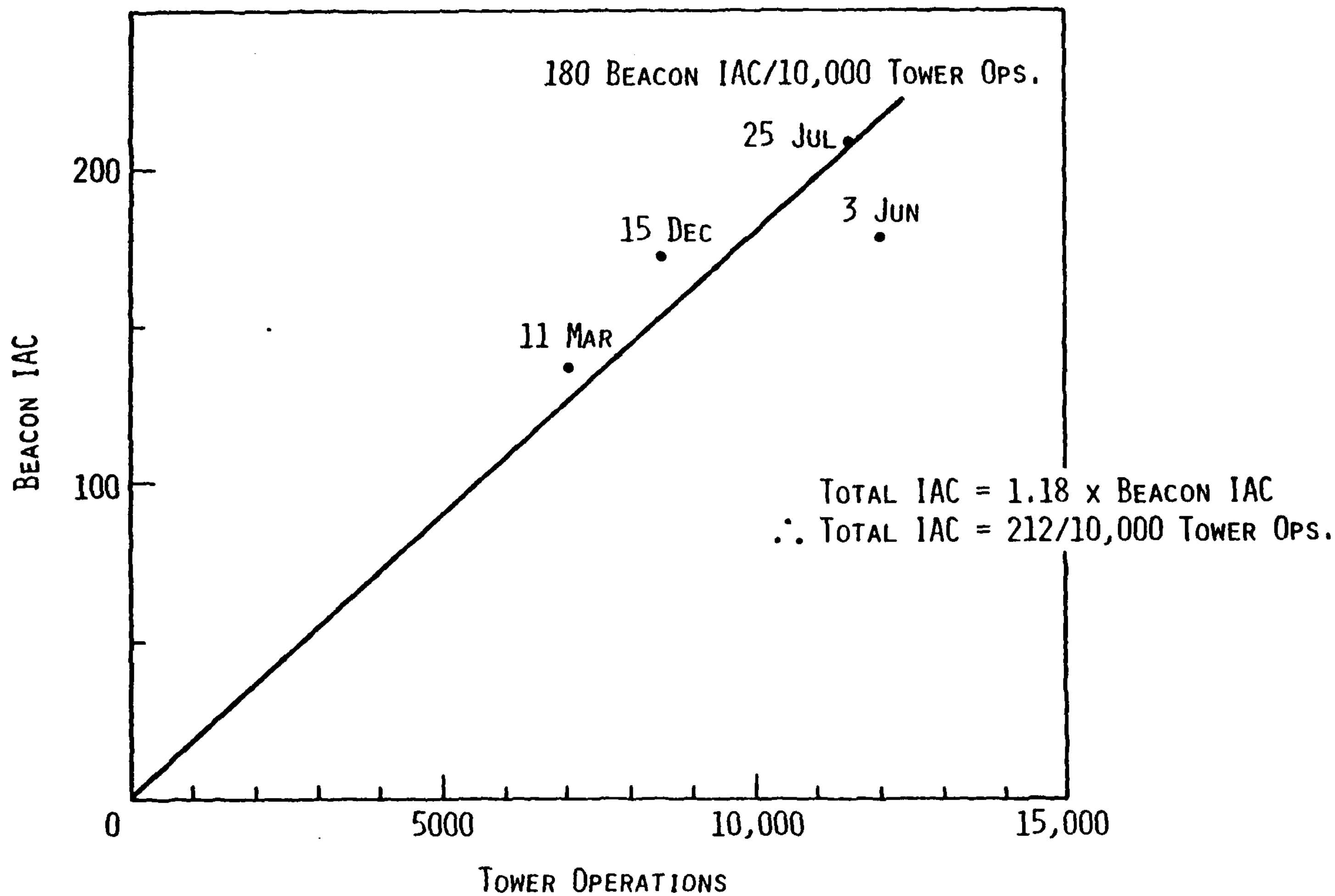


VARIATION OF IAC WITH OPERATIONS

The instantaneous airborne count (IAC) as measured by the flight data is compared with the total daily operations of the 17 towers in the Los Angeles Basin. A remarkably consistent relation was observed. Accounting for the fraction of non-transponder aircraft, one sees that an IAC of approximately 212 aircraft corresponds with 10,000 tower operations, and the relation is linear.

This together with the relation between IAC and density already established, provide the rules needed to project to future environments.

VARIATIONS OF IAC WITH OPERATIONS



SUMMARY OF PRESENT ENVIRONMENT

- PEAK DAY IS 19 JANUARY 1980 WITH 16,868 TOWER OPERATIONS
- ESTIMATED IAC = 212(16,868/10,000) = 358 AIRCRAFT
- RESULTING PEAK DENSITY WITHIN 5 NMI RADIUS CELL = .23 AC/NMI^2
  10 NMI RADIUS CELL = .12 AC/NMI^2

FUTURE GROWTH PROJECTIONS

The FAA supplied a forecast of the yearly operations of the 17 Los Angeles Basin towers. There were summed and compared to the yearly data available from the base year of 1980. The growth, which is clearly an estimate, amounts to a little over 3% per year. These estimates, furthermore, are in agreement with the data used in the recent National Airspace Plan.

While IAC has been shown to be proportional to daily tower operations, we will extrapolate it for future years on the basis of the only operations forecast available, yearly operations.

FUTURE GROWTH PROJECTIONS

FAA PROJECTIONS	YEAR	ANNUAL LA BASIN OPS AT TOWERED AIRPORTS	IAC
	1980	5.07M	358
	1985	5.50	388
	1990	6.40	452
	1995	7.90	558
	2000	9.73	687

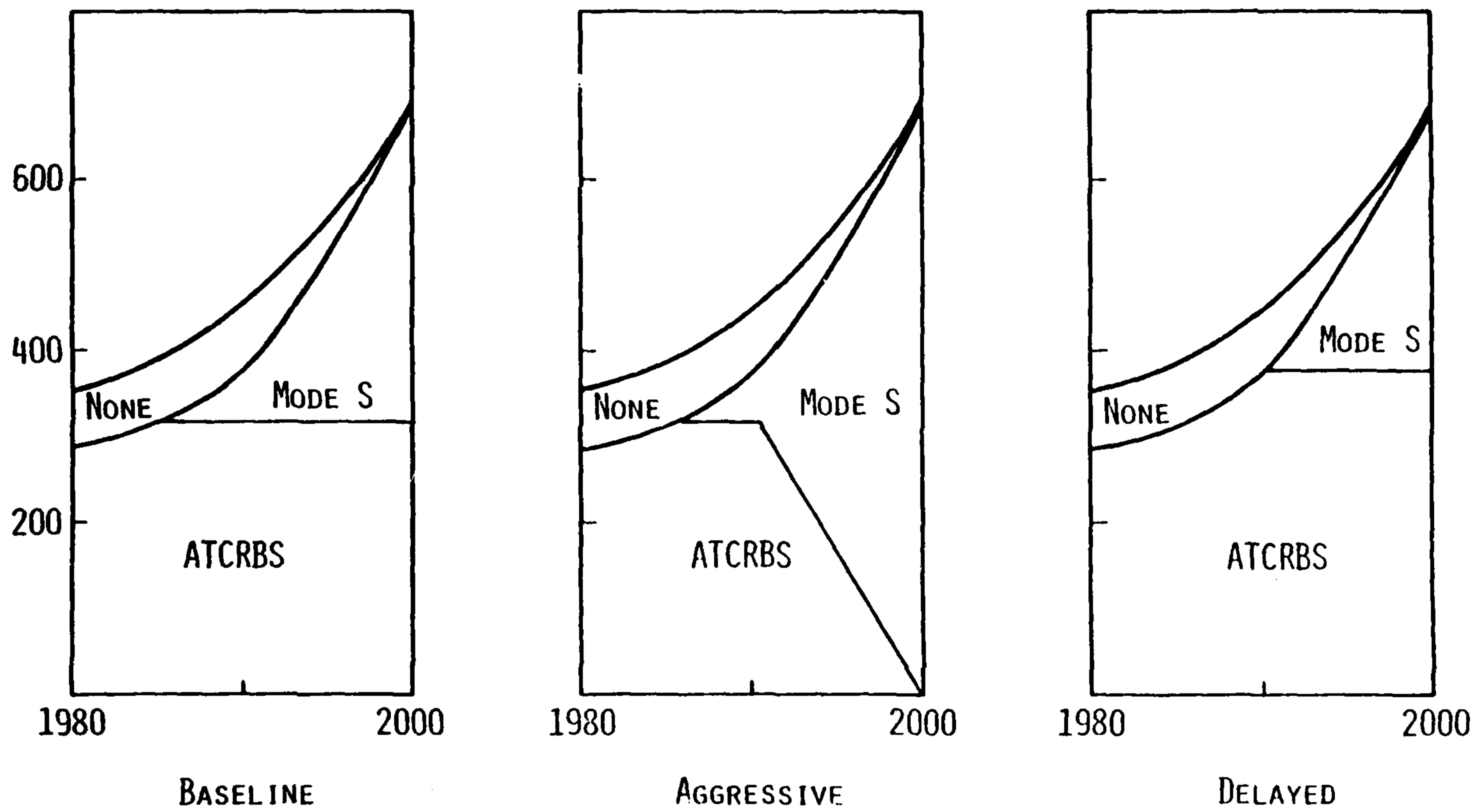
TRANSPONDER EQUIPAGE SCENARIOS

Having the projected IAC for the future, we now need to know how to divide the airborne population into non-transponders, ATCRBS transponders, and Mode S transponders. Any assumption can be postulated and the results evaluated. For this study three different scenarios were devised - baseline, aggressive, and delayed.

All three scenarios assume that all new aircraft have transponders so the number of non-transponder aircraft remains constant until 1990; after that time, they decrease to zero in 2000.

The baseline scenario assumes all new transponders after 1985 are Mode S; the delayed scenario makes that date 1990. The aggressive scenario replaces ATCRBS transponders starting in 1990 and completes the job by 2000.

TRANSPONDER EQUIPAGE SCENARIOS



ICAS ENVIRONMENT

BASELINE	IAC	NO TRANSPONDER	MODE S	ATCRBS	ATCRBS* DENSITY	BEACON* DENSITY
1980	358	55	0	303	.20	.20
1985	388	55	0	333	.22	.22
1990	452	55	64	333	.22	.22
1995	558	28	197	333	.22	.34
2000	687	0	354	333	.22	.45
AGGRESSIVE						
1980			0	303	.20	
1985			0	333	.22	
1990			64	333	.22	
1995			363	167	.11	
2000			687	0	0	
DELAYED						
1980			0	303	.20	
1985			0	333	.22	
1990			0	397	.26	
1995			133	397	.26	
2000			290	397	.26	

*DENSITY BASED ON 5 NMI CELL RADIUS
DENSITY AT 10 NMI CELL IS 1/2 THAT OF 5 NMI CELL

CONCLUSIONS

- THE PEAK VALUE OF DENSITY OBSERVED WAS .14 AC/NMI^2 (5 NMI RADIUS), WHILE THE PREDICTED PEAK IN YEAR 2000 IS .45 AC/NMI^2.

- THIS MAXIMUM VALUE IS AN UPPER BOUND
  - AIRSPACE SATURATION EFFECTS WERE NOT OBSERVED, AND SO ARE NOT INCLUDED IN THE MODEL.
  - GROWTH IN OPERATIONS IS ASSUMED TO OCCUR UNIFORMLY ACROSS THE PRESENT MIX OF AIRCRAFT.
  - ALL NEW AIRCRAFT ARE ASSUMED TO HAVE TRANSPONDERS.

- THE RESULTING MAXIMUM PEAK ATCRBS DENSITY UNDER THE WORST SCENARIO IS .26 AC/NMI^2 (5 NMI RADIUS) AND IS NOT VERY SENSITIVE TO THE ASSUMPTIONS OF DEPLOYMENT.

Surveillance Techniques for Minimum TCAS II

Dr. Jerry D. Welch

12 October 1982

Lincoln Laboratory
Massachusetts Institute of Technology
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Slide 1

TOPICS TO BE DISCUSSED

This talk and the one that follows update one of the talks given at the last TCAS Symposium that presented techniques to achieve air-to-air surveillance in high density airspace. These techniques can be thought of as improvements to the baseline omnidirectional TCAS system covered in the first part of the RTCA MOPS.

I will start with a review of the surveillance requirements for TCAS II and then focus separately on Mode S and ATCRBS surveillance. Discussion of interference limiting and a summary of the TCAS II design as now envisioned will follow.

The following presentation will describe the efforts to validate these techniques.

Slide 2

TCAS II SURVEILLANCE REQUIREMENTS

The surveillance requirements for TCAS II are defined in detail in the RTCA MOPS for TCAS II. The slide shows part of a table from that document. It indicates that 90% of the time minimum TCAS II equipment should be able to detect and track a target closing at a speed of 1200 kt early enough to provide a timely warning to the pilot in a traffic density of 0.06 (about 19 aircraft within a 10-mile radius). As the traffic density increases, the surveillance range is reduced such that at a density of 0.3 (about 94 aircraft in a 10 mile radius), it has a 90% probability of establishing a timely track on an aircraft closing at 500 kt. These requirements assume that at least 25% of the 94 aircraft are Mode S equipped, that all ATCRBS targets have MTL's within specification limits, that all antenna gains are within 3 dB of nominal, and that the number of other TCAS II aircraft within range does not exceed that given in the right-hand column of the table.

The requirements in the table are minimum requirements for both ATCRBS and Mode S aircraft. Balanced against these detection requirements are limitations on false alarms. The false track rate for Mode S targets is always zero because of the parity protection on the Mode S link. The allowable ATCRBS false track rate is 0.2%. This rate has been achieved in low density operation with omnidirectional TCAS II equipment. It is necessary to control false tracks so that this rate is never exceeded in any traffic density.

Another requirement on TCAS II equipment is the generation of bearing estimates on target aircraft and the transfer of own bearing to conflicting aircraft equipped with TCAS I. This bearing determination should be accurate enough to allow a pilot to locate another aircraft visually. The bearing estimates should thus be accurate to about one clock position. This is consistent with an rms error of about 10 degrees. Experience with experimental bearing estimation equipment indicates that an rms error of 8 degrees is feasible.

If the bearing estimates are used to provide proximity warnings to the pilot of the TCAS aircraft as well as for crosslinking data to TCAS I aircraft, it is recommended that TCAS II also include a capability for tracking aircraft that do not have encoding altimeters. The presence of these aircraft can then be announced to the pilot on a plan-position indicator.

A final requirement of TCAS II is that it accomplish all of the above with a minimum of transmissions. Regardless of the number of aircraft or TCAS II units in an area, all of the TCAS II equipments together should never result in more than a 2-percent reduction in the ability of nearby transponders to reply to ground-based interrogators. This interference limiting requirement is one of the more challenging constraints on TCAS II in dense environments.

Slide 3

MODE S SURVEILLANCE

Since TCAS tracks Mode S aircraft by transmitting individual interrogations to each aircraft of interest, it is important that TCAS II perform Mode S surveillance as efficiently as possible. TCAS II initially detects the presence and the discrete address of a Mode S transponder by listening to the replies generated by that transponder in response to other interrogations. If it has not replied within the last second, the transponder generates a spontaneous reply known as a squitter. These replies also contain the altitude code of the aircraft. If the squittering aircraft is far away in altitude, TCAS II need never interrogate. Mode S aircraft well above or below the TCAS II aircraft are tracked simply by passively monitoring their replies.

If a Mode S target is near in altitude, TCAS II must interrogate it at least once to determine its range. If the aircraft is not an immediate threat, TCAS II can withold its next interrogation until the target could possibly come close enough to become a threat. Such a target is called "dormant". When a target comes close enough in range and altitude, it is regularly interrogated. If one of these roll call interrogations fails to elicit a reply, it may be repeated to assure continuous tracking.

Slide 4

MODE S SURVEILLANCE IMPROVEMENTS IN HIGH DENSITY

Several steps can be taken to increase the efficiency of Mode S surveillance in dense airspace. The interrogation rate is reduced by decreasing the sensitivity of the TCAS II receiver during squitter listening periods. This reduces the number of detected squitters and is consistent with the target speed reduction inherent in higher traffic densities. Mode S replies are occasionally corrupted during transmission in such a way that TCAS II is led to believe that there are more Mode S transponders in the vicinity than really exist. This results in wasted interrogations to non-existent transponders. Recent studies indicate that this can be a major

problem in high density airspace. To reduce this problem, TCAS waits to receive two replies from the same address within a fixed correlation time before it interrogates that address. It also helps to carefully "filter" each reply to assure that it conforms to the proper format. A short correlation time and a narrow altitude band also reduce the number of wasted interrogations. Unfortunately, the most common error is a one-bit change in the reply; so duplicate erroneous addresses still occur after all these fixes. This problem would be completely eliminated by using what is known as the "all call" format for squitters. In the all call, the transponder address is protected by parity such that errors can both be detected and corrected. This solution is currently being investigated.

Additional information can be used to reduce the interrogation rate for dormant targets. The low-density BCAS design used only the maximum airspeed capability of the two aircraft to derive a dormancy time. The more information there is available about the position and relative motion of a dormant target, the longer TCAS II can wait beween range measurements.

Finally, the number of interrogations needed for roll-call tracking can be reduced by accounting for the speed reductions in high density and reducing the roll-call range and interrogation power. The reinterrogation rate for roll call targets can also be reduced by error correction.

Slide 5

GARBLE REDUCTION TECHNIQUES - HIGH DENSITY

When TCAS II operates in higher traffic densities, the ATCRBS synchronous garble problem increases. The main techniques for combating ATCRBS synchronous garble in high densities are directional interrogations and finer whisper-shout levels. Minimum TCAS II employs a four-beam antenna that transmits sidelobe suppression pulses from a control pattern to reduce the effective beamwidth. The whisper-shout sequence transmitted differs for the forward, aft, and side beams. Higher power and more whisper-shout steps are transmitted in the forward direction where the detection range must be greater to handle higher closing speeds. The combination of sidelobe control transmissions (which rely on the control of pulse amplitude ratios) and whisper-shout transmissions (which cause transponders to reply only to interrogations received near the transponder minimum triggering level) has uncovered some unexpected effects that required minor surveillance modifications to TCAS II. The consequence of these new effects will be one of the major topics discussed in the next talk.

Slide 6

TRACKING ALTITUDE-UNKNOWN TARGETS

As noted earlier, it is important to account for ATCRBS transponders that are not equipped with encoding altimeters if TCAS II is used to provide a traffic advisory service analogous to the service currently provided by air traffic controllers.

When altitude-reporting ATCRBS aircraft are tracked, the altitude code is used for reply correlation. When there is no altitude code, TCAS II must rely solely on range. For nearby targets, the accuracy of a range-only tracker can be improved if the tracker takes advantage of the fact that for non-accelerating encounters, the square of the target slant range is a quadratic function of time with a well-behaved first derivative, whereas linear range rate exhibits strong apparent accelerations. Thus it is recommended that minimum TCAS II track all short-range altitude-unknown targets in R^2 with a parabolic least-squares tracker.

Slide 7

INTERFERENCE LIMITING ALGORITHM

At the previous TCAS Symposium a set of four inequalities were presented as the means for assuring that no transponder is turned off by TCAS II activity for more than 2 percent of the time and for assuring that TCAS II does not contribute to an unacceptably high fruit rate. It is necessary for each TCAS II unit to account for other TCAS II aircraft in its vicinity when limiting its own transmissions. As the number of TCAS II aircraft increases, the interrogation allocation for each of them must decrease. Thus, every TCAS II unit must monitor the number of other TCAS II units (NT) within detection range. This information is then used along with the knowledge of own interrogation rates and powers (ΣP) and own mutual suppression rates (ΣM) to determine the maximum allowable power and sensitivity for ATCRBS and Mode S interrogations within the next surveillance update interval.

Since this process involves a feedback loop whose characteristics are determined by the dynamics and spatial distribution of a large number of aircraft, one must be concerned with potential instabilities. The stability and performance of this control loop is being investigated in a comprehensive simulation performed by the Electromagnetic Compatibility Analysis Center of Annapolis, MD.

Slide 8

INTERFERENCE LIMITING CHANGES

Several changes have been made to interference limiting since the last TCAS Symposium. The waveform used to monitor the TCAS II population is now received via the transponder. Originally, this was done by monitoring a special code in the transponder replies transmitted from other TCAS II aircraft. However, since the detection range for transponder replies varies with the ATCRBS fruit rate, it was also necessary to monitor the ATCRBS fruit rate to correct the count of detectable TCAS II aircraft. The result was a crude estimate of the TCAS II count. To improve the accuracy of the TCAS II count in dense airspace, a change was made to require each TCAS II unit to

periodically announce itself via a spontaneous TCAS II broadcast interrogation. Other TCAS II units detect these broadcast interrogations by monitoring messages received by their on-board Mode S transponders.

It has also been determined that one of the 4 original inequalities which was intended to limit Mode S fruit was redundant because Mode S fruit is automatically limited by the inequality that limits the air-to-air suppression rate due to Mode S interrogations. Finally, a number of detailed changes have been made in the time constants, smoothing procedures, and hysteresis parameters of the limiting algorithms to improve the stability of this feedback process.

Slide 9

MINIMUM TCAS II DESIGN

The current minimum TCAS II design is summarized in this table. TCAS II employs a 4-beam directional antenna on top of the aircraft. Transmit sidelobe suppression is used to control the effective interrogation beamwidth. The angle-of-arrival of the detected aircraft is determined by means of an omnidirectional bearing estimation technique. The role of the bottom antenna is limited in the TCAS II design to minimize multipath-generated false targets. A high-resolution whisper-shout sequence is used. Although a total of 83 interrogations are transmitted each second, the interference limits are satisfied by transmitting most of these interrogations at very low power. The peak power in the sidebeams is 4 dB below the peak power transmitted in the forward direction. The peak power aft is 9 dB below the forward power.

Mode S surveillance is accomplished by listening to squitters alternately on the top and bottom antennas. The current design splits the listening time equally between top and bottom. The consequences of biasing listening in favor of the top antenna are under active consideration.

At the previous TCAS Symposium it was noted that the tendency for TCAS interrogations to reflect back and interrogate the transponder on board the TCAS II aircraft might require a specially designed Mode S transponder for all minimum TCAS II installations. It has since been determined that the duration of the backscatter reception is sufficiently short that blanking can safely be used to prevent the on-board transponder from replying to TCAS II interrogations. The blanking pulses can be kept short enough so that the total blanked time in the transponder never exceeds the bounds established by the interference limiting inequalities.

SLIDE 1

Surveillance Techniques For Minimum TCAS II

J.D.Welch, M.I.T. Lincoln Laboratory

Topics To Be Discussed

- TCAS II surveillance requirements
- MODE S surveillance in high density
- ATCRBS surveillance in high density
- Interference limiting
- Current TCAS II design

SLIDE 2

TCAS II Surveillance Requirements

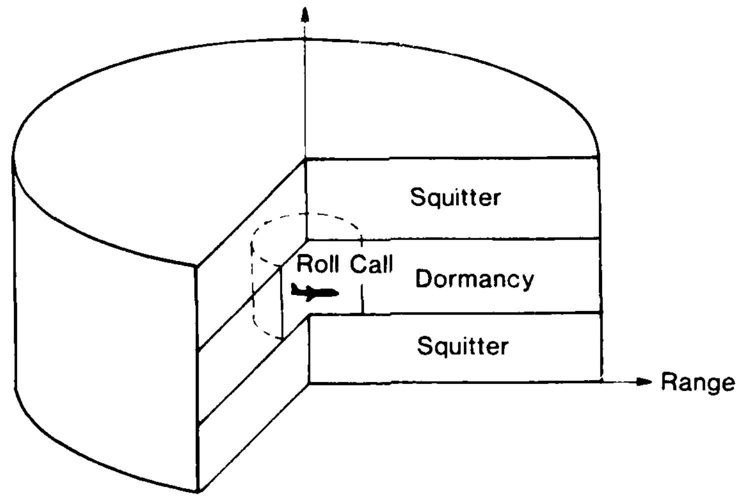
- TCAS II will meet or exceed the following:

CLOSING SPEED	MAX TRAFFIC DENSITY FOR WHICH SUCCESS PROB. = 90%	MAX NO. OF OTHER TCAS II WITHIN 30 NMI
1200 KT	0.06 AIRCRAFT/NMI^2	13
500 KT	0.30 AIRCRAFT/NMI^2	67

- TCAS II will limit false ATCRBS tracks to less than 1 in 500 track-seconds
- TCAS II will provide target bearing estimation with 8° rms accuracy or better
- TCAS II will degrade ground surveillance by no more than 2%

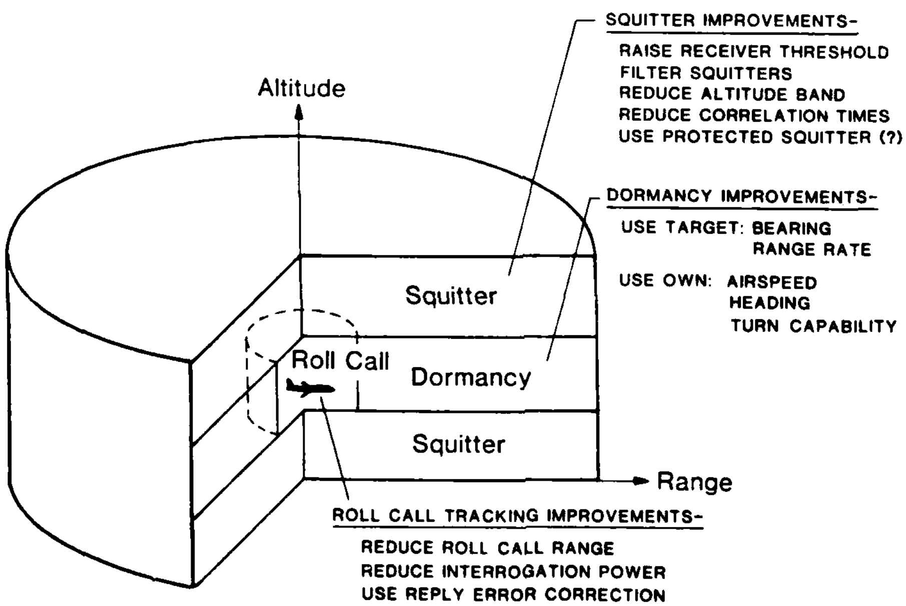
SLIDE 3

MODE S Surveillance



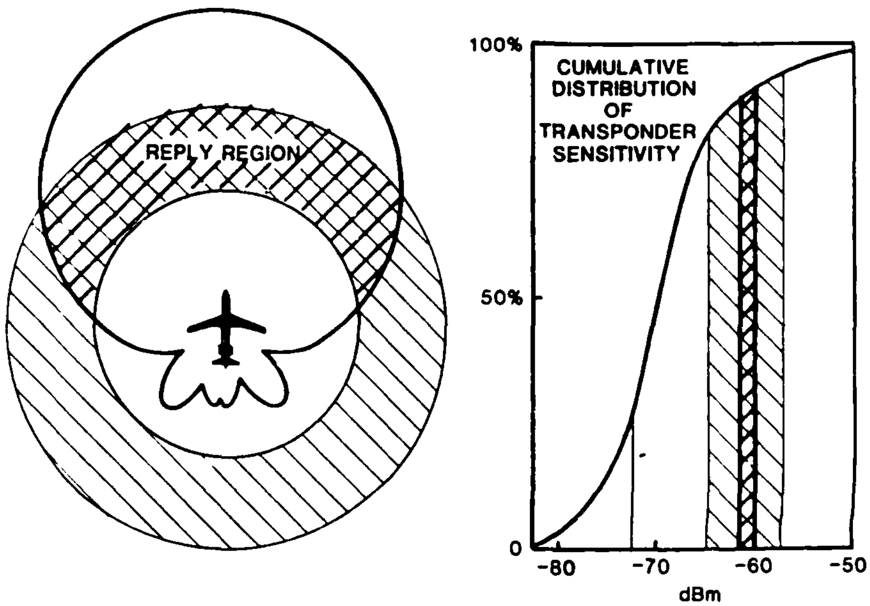
SLIDE 4

MODE S Surveillance Improvements In High Density



SLIDE 5

GARBLE REDUCTION TECHNIQUES - HIGH DENSITY

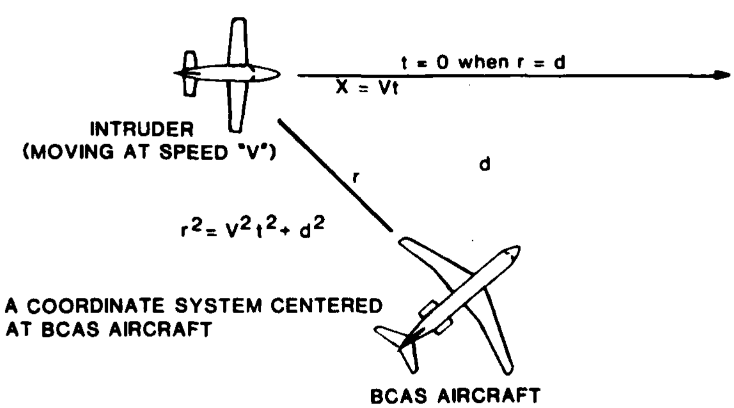


SLIDE 6

Tracking Altitude-Unknown Targets

Unavailability of altitude code reduces reply correlation accuracy

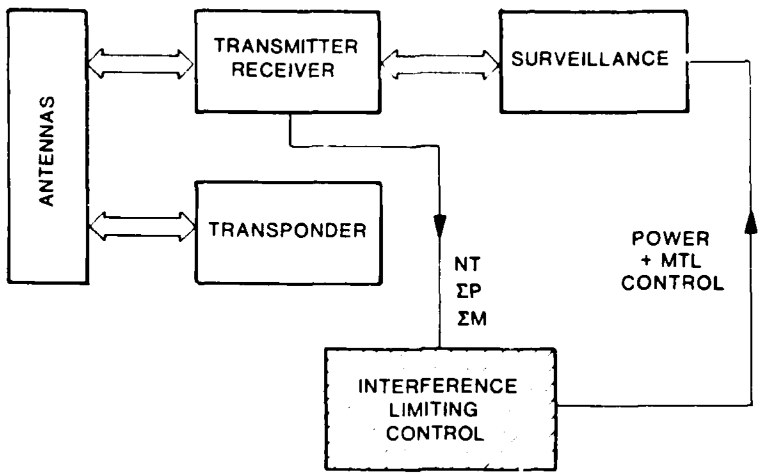
For non-accelerating encounters, square of range is quadratic in time



Parabolic , least-squares tracking of r^2 improves predictions at closest approach and allows reliable tracking when altitude correlation is available

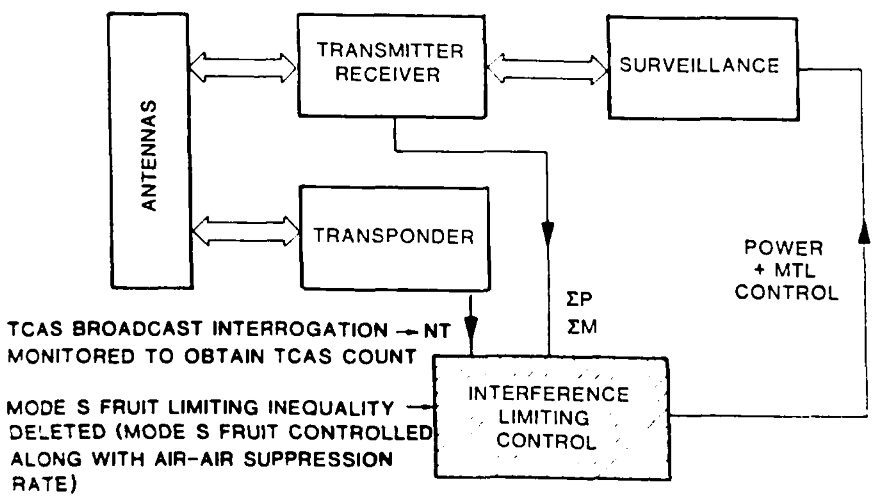
SLIDE 7

Interference Limiting Algorithm



SLIDE 8

Interference Limiting Changes



SLIDE 9

Minimum TCAS II Design

TOP ANTENNA	4 Beams, 90°, Transmit SLS, Omni AOA on reception	
BOTTOM ANTENNA	Omni monopole	
WHISPER/SHOUT	Top-Forward	24 Levels
	Top-Right	20 Levels
	Top-Left	20 Levels
	Top-Aft	15 Levels
	Bottom	4 Levels
COVERAGE IN AZIMUTH	Side beams -4 dB, Aft beam -9 dB	
SQUITTER RECEPTION	1 Receiver time shared between top & bottom	
MUTUAL SUPPRESSION	Ordinary interrogation decoder, 70 μs MODE C top, 90 μs MODE C bottom, 60 μs MODE S	

Validation of Minimum TCAS II Surveillance Performance

Dr. William H. Harman

12 October 1982

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Slide 1

TCAS II SURVEILLANCE - VALIDATION ACTIVITIES

When the TCAS II high density techniques were described at the January Conference, it was pointed out that further work would be needed in a number of areas before these techniques could be considered to be validated. Plans were presented for this further work, including airborne measurements in some areas and simulation work in others. The following is a report of the progress of that work during the intervening nine months.

The slide outlines the development activities. The most prominent issues are Mode C directional interrogation and whisper-shout, which are the main techniques for avoiding synchronous garble in high density airspace.

This work is being followed by the construction of a real-time TCAS II unit, which will give the opportunity to test the techniques all together and in real-time.

Slide 2

PHANTOM MODE A INTERROGATION

The work to assess directional interrogation is based primarily on airborne measurements. To make this possible an experimental directional interrogator was built. Since the initial analytical work had indicated that four beams would be sufficient, a four beam design was undertaken, and was built by Dalmo Victor. The equipment includes an antenna that can transmit in four directional patterns, along with a P2 control pattern accompanying each beam, and an omnidirectional pattern for comparisons with omni whisper-shout. The unit also includes: a transmitter having provisions to switch among the different beams; an improved whisper-shout attenuator, so that whisper-shout and directional interrogation can be tested together, and a magnetic tape recording capability enabling a detailed study of all replies triggered by these interrogations.

As airborne data became available, one of the first things observed was a problem with unwanted replies occurring at a shorter range relative to the correct replies from certain aircraft. It was soon realized that this effect was due to a phantom Mode A interrogation, illustrated in the slide. Evidently the transponder will intermittently detect the combination of S1 and P2, which are 8 μs apart (in the initial experimentation), and will reply in Mode A. This effect had not been anticipated; to first order, a transponder would detect both or neither of the two suppression pulses S1 and S2, which are of equal power. When they are received near threshold, however, it becomes possible to intermittently detect S1 and not S2. Whenever this happens the transponder does not suppress, and continues to search for a pulse to complete an interrogation. When outside of the mainbeam, as in this example, P2 is large and readily furnishes the second part of a Mode A interrogation.

In considering possible changes to avoid this problem, a single-pulse suppression seems particularly appropriate. The single pulse suppression waveform is a way of implementing whisper-shout using just one suppression pulse spaced 2 μs before P1. This approach eliminates the phantom Mode A problem and reduces by one the total number of interrogation pulses transmitted.

The single pulse suppression waveform was implemented and tested at Lincoln Laboratory using an omnidirectional rooftop antenna. Using a technique of rapidly switching back and forth between 2-pulse suppression and 1-pulse suppression, it was found that the new technique works well.

This change has subsequently been implemented in the Dalmo Victor equipment. In airborne testing the whisper-shout suppression performance of this waveform seems satisfactory, and the phantom Mode A problem has been eliminated.

Slide 3

BEAM LIMITING NEAR THRESHOLD

In understanding the mechanism of directional whisper-shout, a second important discovery concerns the sidelobe suppression, or beam limiting action for receptions near transponder threshold. Previous plans allowed for a 9 dB SLS ratio. That is, the interrogator design allowed for the possibility that some transponders do not reply when P2 is received nearly 9 dB below P1, thus it was planned to transmit P2 at a power level low enough to insure that P2 < P1 - 9 dB everywhere in the mainbeam.

More recently it was realized that for receptions near threshold as is the important case when whisper-shout is used, reply is very likely even when P2 is just a few dB below P1. It was therfore concluded that the transmitted P2 power should be increased. The experimental equipment has since been changed, increasing P2 power to the maximum value readily achievable with this equipment, namely P2 = P1 as transmitted. Higher levels of P2 are worth considering as well.

It follows that the uniformity of reply beamwidths is improved relative to what was originally expected. The effective reply beamwidth has been recalculated under the new conditions, based on the antenna patterns of the experimental four beam antenna, giving the results:

Effective reply beamwidth = 122°

Degarbling factor = 360°/122° = 2.9

Slide 4

LATE MODE C REPLIES

Further examination of airborne data revealed another unexpected problem, characterized by unwanted replies appearing at slightly longer range than the correct replies from certain transponders. The range difference is 0.16 nmi which corresponds to 2 μs. After some study, it became apparent that the reply mechanism (illustrated in the slide) is due to a Mode C detection triggered by the combination of P2 and P4. This occurs intermittantly when the pulses are received near threshold and when the target is outside of the mainbeam.

It was concluded that this effect could be eliminated by incorporating a filter for these late replies in the surveillance processor. Thus these unwanted replies will be present in the collection of all replies and will contribute to synchronous garble and will therefore reduce the degarbling effectiveness of the directional interrogation technique. An initial estimate of the incidence of these unwanted replies is an increase in the total reply count by 15%. Thus the performance of the directional transmit technique is not significantly degraded.

Slide 5

DIRECTIONAL INTERROGATION -- AIRBORNE DATA

Here is an example of the data recorded by the Dalmo Victor equipment while airborne. This target flew by from front-to-back, passing to the left, at a slightly lower altitude. The results in the slide show that the target replied appropriately first to the front beam, then to the left beam, and finally to the back beam. In the transitions from beam-to-beam, there is a small amount of overlap, with the result that the sequence of replies continues unbroken through these transitions.

Thus the spatial partitioning expected from directional interrogation is evident, at least qualitatively, in the data. A quantitative assessment of the degarbling is in progress.

Slide 6

DIRECTIONAL INTERROGATION - SUMMARY

The airborne measurements to date have led to the discovery of several important mechanisms and have indicated the need for some changes to the TCAS II design. Furthermore, airborne results have demonstrated that spatial partitioning is achieved, and these observations tend to increase the level of confidence that directional whisper-shout will be effective.

Slide 7

WHISPER-SHOUT SEQUENCES

The whisper-shout technique by itself has also been under study. This illustration shows the 4-level form of whisper-shout used in BCAS, in comparison with the more capable 24-level form of whisper-shout proposed for TCAS II. The most significant attribute of a whisper-shout interrogation is its bin width, which is the dB difference between the interrogation and the associated suppression. It is to be expected that if bin width is decreased, the average number of aircraft that reply to the one interrogation will be decreased, which is the desired alleviation of synchronous garble. The bin width in the BCAS sequence was 9 dB, whereas in the TCAS II sequence it alternates between 3 dB and 2 dB.

Slide 8

WHISPER-SHOUT DATA

Airborne measurements using several values of bin width were undertaken, to assess the effectiveness of decreasing bin widths. The experiment included a set of 1-dB bins, a set of 2-dB bins, a set of 3-dB bins, and a set of 9-dB bins. All were transmitted in each 1-second period. The results plotted here confirm the general expectation of a substantial improvement as bin width is decreased.

Slide 9

WHISPER-SHOUT COMPARISON

This performance comparison between the two whisper-shout sequences was obtained by operating with both sequences simultaneously, that is, alternating rapidly between the two sequences so that both types of data are collected in each 1-second period. In this typical example, a significant improvement is evident, particularly in regions where several aircraft exist at nearly the same range.

Slide 10

SURVEILLANCE FALSE ALARMS

At the time of the BCAS Conference in January 1981, there had been no instances in which a false track caused a false alarm or modified a real alarm. This was encouraging since the airborne testing had accumulated several hundred hours of experience by that time. Even so, it was realized that false tracks do occur and that therefore some false alarms would eventually occur. In the time since then, the airborne experience has increased by many more hundreds of hours, and now several instances of false and modified alarms have been observed. The Piedmont data, for example, includes about 900 hours, and in this data there is one instance of a modified alarm and no instances of isolated false alarms. In addition, a considerable amount of testing has been done by the FAA Technical Center on the East Coast

and in the Chicago area, and by Lincoln Laboratory in the Boston area. In this additional data there have been 8 instances of false alarms.

These false alarms have been studied individually and categorized according to the mechanism causing the false track. It was found that the largest single source of false alarms was multipath. That is, for a real aircraft target producing a real track, a reflection from the ground or water gave rise to a second track.

Since multipath induced false tracks are mainly associated with the TCAS II bottom antenna, it became appropriate to consider reducing the role of the bottom antenna. By reprocessing the recorded data from all the instances of multipath false alarms, it was found that 4 of the 5 occurrences would have been eliminated by deleting the 3 highest power bottom interrogations (that is, by reducing bottom antenna interrogation power by 18 dB).

Slide 11

ROLE OF BOTTOM ANTENNA

In considering a reduction of the role of the bottom antenna to reduce false tracks, it is necessary to know what the effect would be on the reliability of tracking real aircraft.

An experiment was set up to gather airborne data for a performance comparison between a design using top and bottom antennas equally and a design that reduces the role of the bottom antenna. The interrogation sequences to be compared were selected to have the same total number of interrogations and the same power-sum (both of which are quantities constrained by interference limiting). The results of several measurements showed that the reduced-bottom design performs nearly as well as the equal-use design, having surveillance reliability that is less by only about 2 or 3 percent. In the example shown in the slide, the reduced-bottom design is the whisper-shout sequence proposed for TCAS II, and here the performance difference is just 2.3 percent (of track seconds for aircraft within ± 10° in elevation angle).

Since the reduced-bottom design achieves a significant reduction in false tracks while tracking real aircraft almost as well, it has been concluded that this is a worthwhile feature to be included in TCAS II.

Slide 12

PERFORMANCE WITH REDUCED POWER

In very high density airspace, closing speeds are reduced and thus the range requirements of TCAS II are reduced. Under these conditions it should be possible to reduce the interrogation power level. Indeed, to conform with the interference limiting standards, it will be necessary for such a power reduction. The initial design of TCAS II presented at the FAA Conference this past January was based on estimates of surveillance reliability at reduced range with reduced power. These initial estimates were analytically derived

(ref., "Effects of RF Power Deviations on BCAS Link Reliability", M.I.T. Lincoln Laboratory, ATC-76, 7 June 1977). The plan at that time was to conduct airborne measurements to validate or refine these early estimates.

This airborne data has since been obtained by reprocessing whisper-shout data already recorded, omitting the higher power levels. The airborne results for a 6-dB power reduction are summarized in this slide, together with calculated results representative of the early estimates. The agreement between calculation and measurement is sufficiently good to provide assurance that the basis for the original design was reasonably good. The data shows that when interrogation power is reduced by 6 dB, it is still possible to achieve effective surveillance at ranges up to 5 nmi.

Slide 13

ALTITUDE UNKNOWN

The TCAS II function that tracks altitude-unknown targets was added to the real-time equipment at Lincoln Laboratory about 2 months ago, and so we are beginning to accumulate some experience with its performance. It appears to be working quite well. Here is an example in which three targets are in track, one of which is of unknown altitude.

Slide 14

MODE C PERFORMANCE ESTIMATES

An overall performance estimate will serve to summarize the current understanding of the performance mechanisms in Mode C. This estimation brings together the things learned from the separate studies of directional interrogation, whisper-shout, reduced role of bottom antenna, and effects of power reduction.

This assessment begins by reviewing the performance of omnidirectional surveillance using the basic 4-level whisper-shout on both top and bottom antennas. The data in the slide was taken from BCAS airborne measurements (reported at the January 1981 BCAS Conference).

The next case is omnidirectional, but uses

- 24-level whisper-shout, top antenna
- 4-level whisper-shout, 18 dBm down, bottom antenna

To account for the more capable form of whisper-shout, the slope of the performance curve has been reduced by the factor 4.5 (which is the ratio of the bin widths, 9 dB and 2 dB). To account for the reduced role of the bottom antenna, the performance curve has been shifted downward by a constant 2.5%.

The next step is to add directional transmission using four beams. To represent this improvement, the slope of the performance curve was further reduced by the factor

$$\left(\frac{360°}{122°}\right) \times \frac{1}{1.15} = 2.6$$

The first factor accounts for the reduction of replies due to spatial partitioning, and the factor of 1.15 accounts for the unwanted increase in replies due to late Mode C interrogation detections.

Slide 15

CONCLUSION

The foregoing summarizes the development actvities in progress for air-to-air surveillance in Mode C. Work is proceeding in parallel to develop Mode S surveillance and interference limiting. Altogether, these development activities are quite extensive in the sense that they cover many areas. Much has been learned in all of these areas, and so the confidence level for successfully achieving the TCAS objectives has improved considerably over the past nine months.

Some key measurements and other tasks, however, have yet to be accomplished. The figure summarizes the plans, including airborne measurements in some cases and simulation work in others, for completing this development program. When completed, this work will be followed by the fabrication of real-time TCAS II equipment and airborne testing of it in high density airspace.

SLIDE 1

TCAS II Surveillance – Validation Activities

W.H. Harman, M.I.T. Lincoln Laboratory

Mode C Surveillance

- Directional interrogation
- Whisper-shout
- False alarms
- Role of bottom antenna
- Power reduction
- Altitude unknown

Mode S Surveillance

- Algorithm improvements
- Address detection

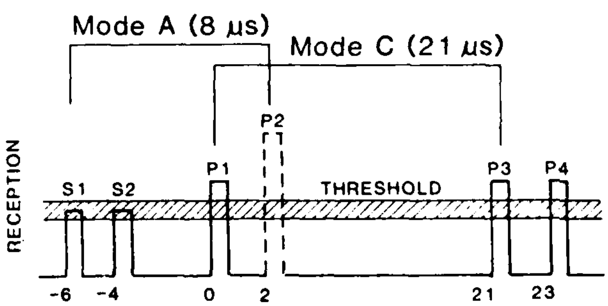
Interference Limiting

- Limiting algorithm
- Limiting standard
- Self suppression

SLIDE 2

Directional Interrogation

PHANTOM MODE A INTERROGATION

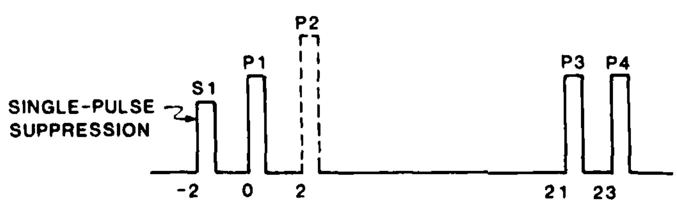


SCENARIO – TARGET OUT OF MAINBEAM

DESIRED REACTION – NO REPLY

ACTUAL REACTION – EARLY MODE A REPLY (INTERMITTANT)

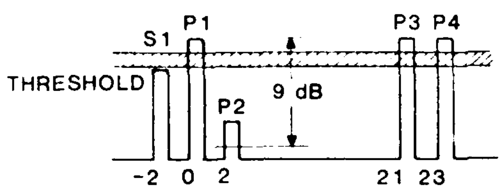
CONCLUSION – CHANGE INTERROGATION WAVEFORM



SLIDE 3

Directional Interrogation

BEAM LIMITING NEAR THRESHOLD



SPECIFICATION

(ATCRBS NAT. STD.):
REPLY OPTIONAL

IN ACTUALITY :

REPLY LIKELY

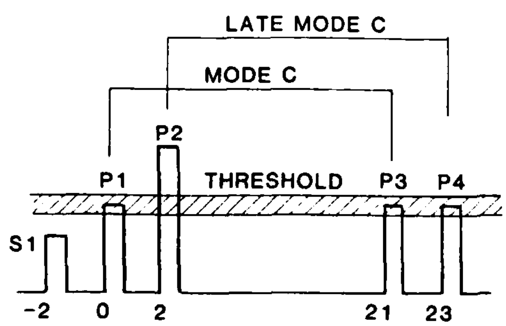
Conclusions – (1) Increase transmitted P2 power

(2) Uniformity of reply beamwidth is improved

SLIDE 4

Directional Interrogation

LATE MODE C REPLIES



SCENARIO – TARGET OUT OF MAIN BEAM

DESIRED REACTION – NO REPLY

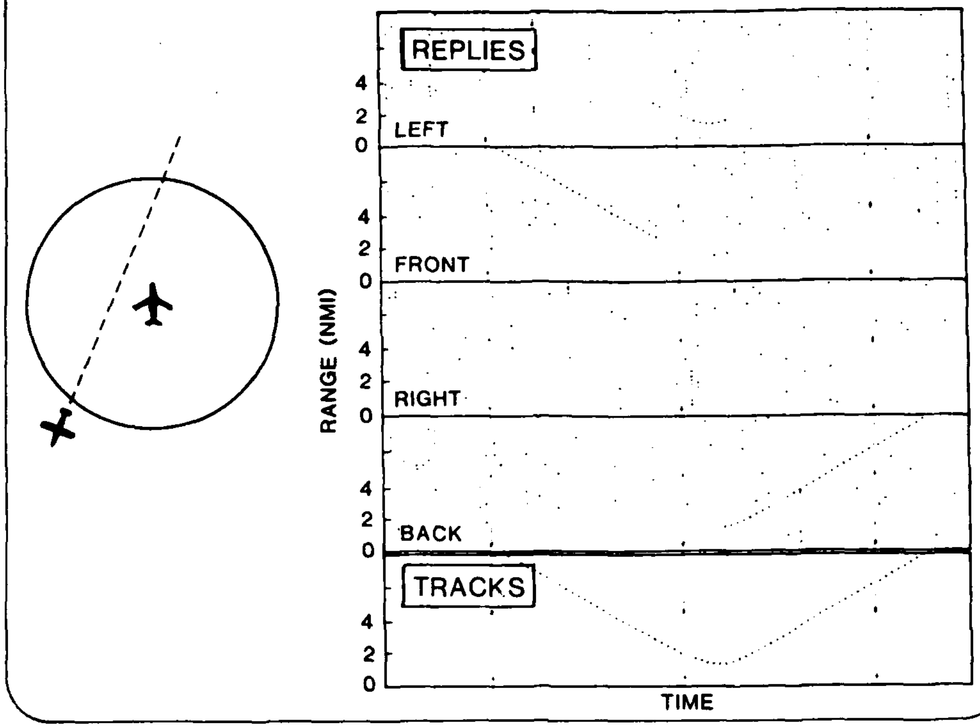
ACTUAL REACTION – LATE MODE C REPLY (INTERMITTANT) ADDS ~ 13%

Conclusions – (1) Incorporate a filter for these in the surveillance tracker

(2) Degarbling effectiveness is reduced

SLIDE 5

Directional Interrogation – Airborne Data



SLIDE 6

Directional Interrogation

SUMMARY

PROGRESS

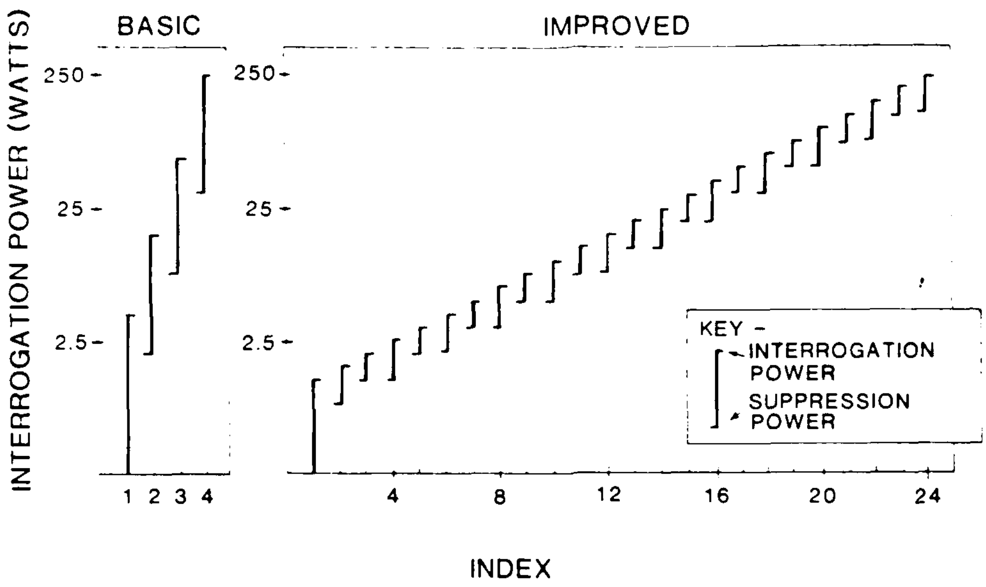
- Airborne measurements begun
- Phantom Mode A
- 1 – pulse suppression
- Beam limiting near MTL
- Late Mode C

PLANS

- Finish debugging
- Airborne meas. in high density

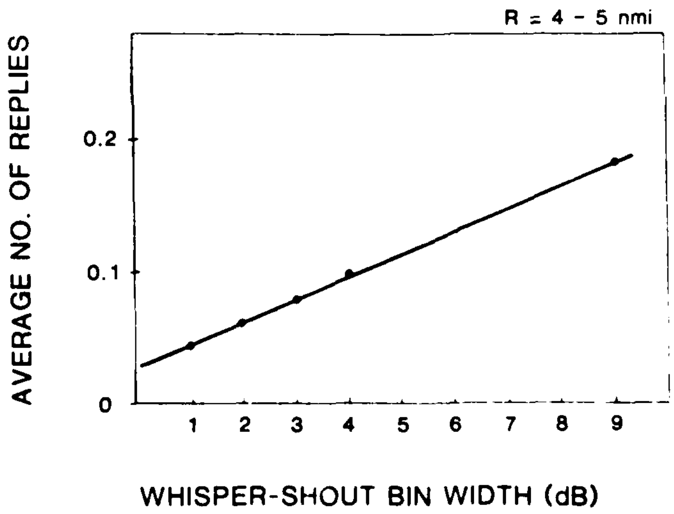
SLIDE 7

Whisper/Shout Sequences



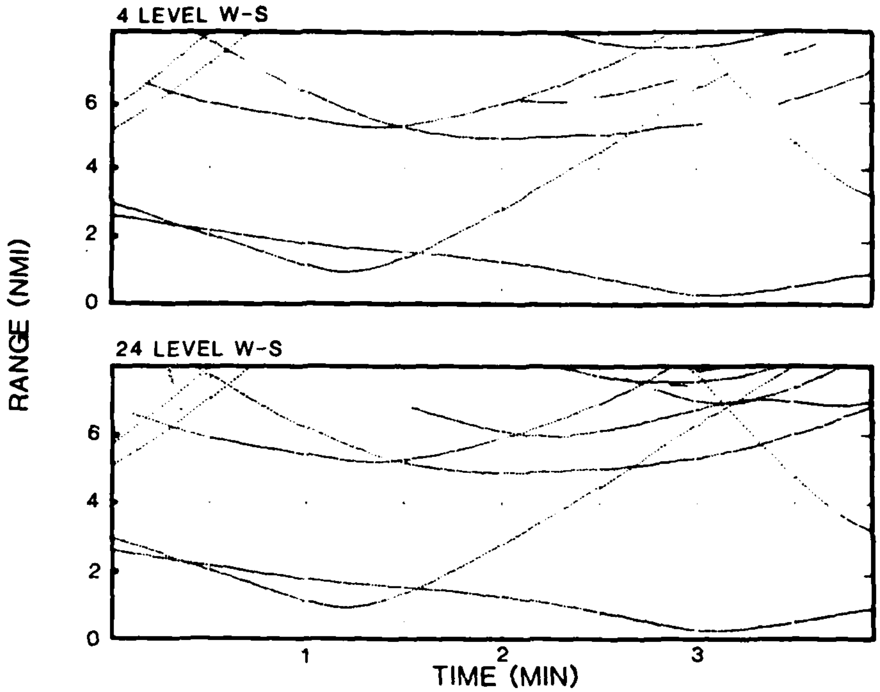
SLIDE 8

Whisper-Shout Data



SLIDE 9

Whisper - Shout Comparison



SLIDE 10

Surveillance False Alarms

	Piedmont data (900 hours)	other airborne data
Isolated false alarms	0	1 - synch. garble 3 - other
Modified real alarms	1 - multipath	4 - multipath

SLIDE 11

Role of Bottom Antenna – Airborne Data

COMPARISON

TOP	14	VS.	24	(BASELINE)
BOTTOM	14		4	

DATA

New York area, 40 min., 13 August 1982

RESULTS

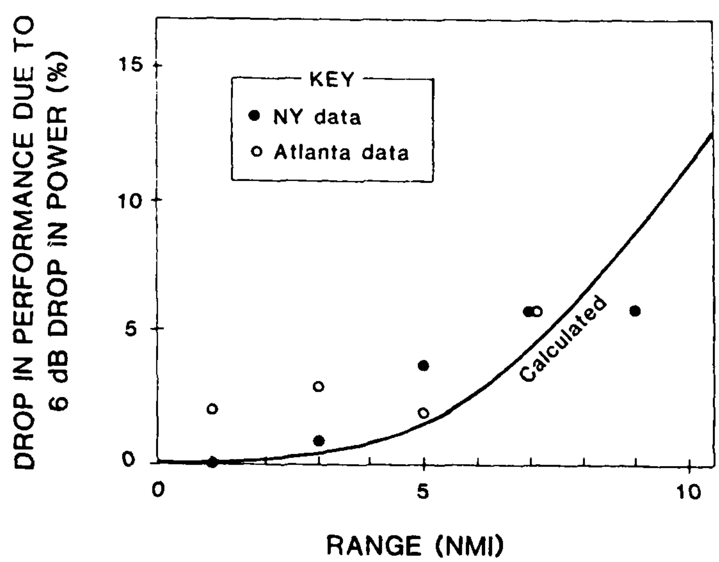
Decreasing role of bottom antenna :
decrease in tracking of real aircraft by 2.3%

CONCLUSION

Adopt 24/4 for TCAS II

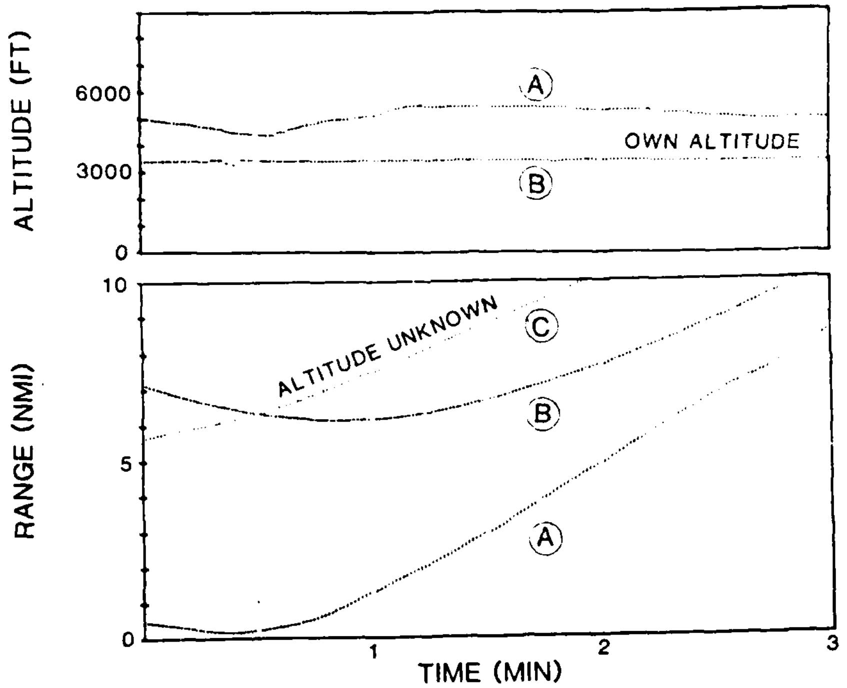
SLIDE 12

Performance With Reduced Power



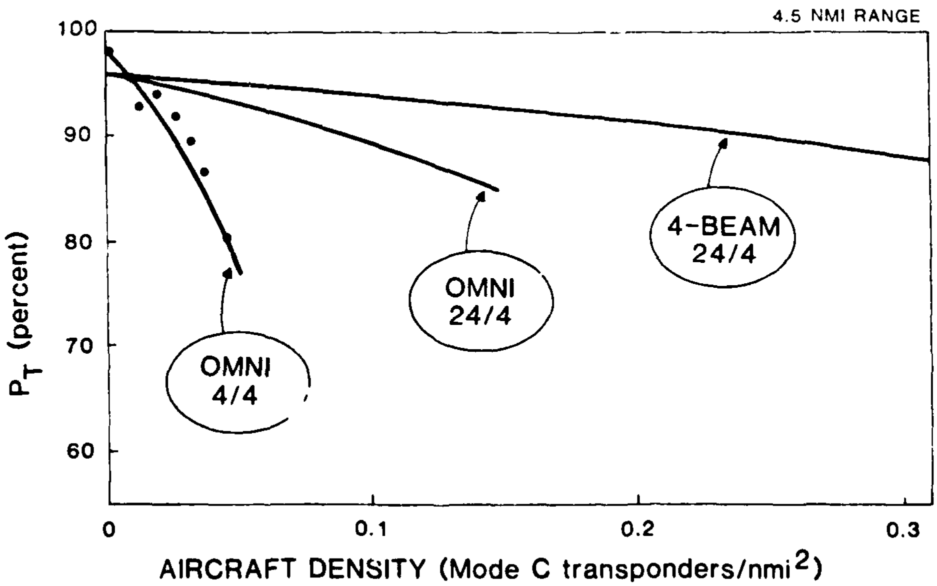
SLIDE 13

Altitude Unknown



SLIDE 14

Mode C Performance Estimates



SLIDE 15

TCAS II Surveillance – Validation Activities

Mode C Surveillance

- Directional interrogation
- Whisper–shout
- False alarms
- Role of bottom antenna
- Power reduction
- Altitude unknown

Mode S Surveillance

- Algorithm improvements
- Address detection

Interference Limiting

- Limiting algorithm
- Limiting standard
- Self suppression

PLANS:

AIRBORNE MEAS.

SIMULATION

AIRBORNE MEAS.

SIMULATION (ECAC)

ENHANCED TCAS-II

13 OCTOBER 1982

J. EMORY REED
THE BENDIX CORPORATION
COMMUNICATIONS DIVISION
BALTIMORE, MARYLAND 21204

Bendix

SLIDE 1 (Cover)

You may remember from the FAA TCAS Symposium held in January of 1982 that a description of the Bendix plan of attack to develop the Enhanced TCAS II was presented. I would like today to bring you up to date on our engineering accomplishments since that time and to describe the very encouraging results we have obtained in some vital areas.

Bendix has been motivated by the challange of developing an operationally acceptable CAS. We feel that this acceptability criteria will probably be satisfied in operational situations on a pilot by pilot basis when and if he finds through normal observation of his CAS system when he is using visual and radio clues to guide his actions, that the CAS resolution is not in conflict with his own decisions. He may find it even more acceptable if the CAS somehow extends his own abilities by providing him information that he would not otherwise have. Toward this goal the Bendix approach has been to apply advanced technology in three main areas, optimized system design, antenna technology and adaptive control.

SLIDE 2

This viewgraph is an attempt to capture the essence of the Enhanced TCAS-II which is characterized by accurate bearing, narrow sectorized interrogation control and tailored system parameters. With these system qualities the possibility of horizontal resolution of confict situations becomes available to extend system performance capability and reduce the incidence of unnecessary evasive maneuvering. The ability of this system to provide traffic advisories with relative motion (that is the indication of the position of the potential threat relative to own aircraft throughout an encounter) reinforces the pilots visualization of the three dimensional situation.

The ability of the Enhanced TCAS-II to intelligently utilize narrow sector interrogations together with receive sidelobe supression, accurate angular location of other aircraft and a few levels of whisper-shout permits operation in the most extreme traffic density projected. The narrow sector interrogation and power contouring also reduces the amount of interference caused by Enhanced TCAS-II interrogations.

SLIDE 3

This viewgraph highlights Bendix accomplishments on the Enhanced TCAS-II contract thus far. First a system concept was created having all of the features I have just discussed. This concept is embodied in an Engineering Model Design Specification.

Secondly a complete computerized simulation has been developed and used to validate the concept. This simulation emulates traffic and consequent elecromagnetic signal environments on a pulse by pulse basis. The basis for the traffic environment is the FAA's Los Angeles Standard Traffic Model containing 743 aircraft, sometimes referred to as the "aluminum cloud". Against this environment the computer program logic has been tested for use in the actual Flight Test Equipment.

Thirdly, an accurate directional antenna has been developed and tested.

And finally we have designed, constructed and are in the final stages of testing of two complete Engineering Model A Enhanced TCAS-II systems which will be flown and tested extensively in FAA 727 aircraft. We expect to deliver the first of these to the FAA Technical Center for installation in November 1982. (The Model A system you may recall has all of the features of the Enhanced TCAS II except for the horizontal maneuver logic.) These will subsequently be upgraded to Model B equipments when the horizontal logic which is being developed by MITRE becomes available and, together with other associated computer program changes is incorporated in the equipment.

SLIDE 4

This illustration shows the organization of the simulation test bed. The area labeled "Environment" incorporates code which precisely represents the LAX Traffic Model with 743 aircraft and the corresponding Radio Frequency Electromagnetic Environment (labeled R.F.E.) which results when that number of aircraft are being interrogated by the ground based ATC Radar Beacon System located in the LAX vicinity together with an aircraft based TCAS population. I want to emphasize that the simulation is not limited to the LAX or any other scenario. Any distribution of traffic can be entered or any special situation placed in the model for study. The RF interference environment is that seen at own aircraft. In addition the location of all aircraft relative to own for each 50 millisecond period is calculated and stored in the Flight Profile File so that appropriate replies can be generated in response to own interrogations.

The operational program algorithms are contained in the Design Simulator which generates commands to the synthesized hardware in the center section telling it what to do and when to do it. The resulting signalling is emulated in this center block and the equivalent replies are returned to the Design Simulator where they are processed as they would be in a real time system. As with the environmental simulator, any TCAS II model could be simulated, however only the Enhanced TCAS-II Model A has been simulated in our FAA contract activity.

All data passed between software modules can be captured and stored for further study if desired. The results of the simulation are displayed for quick look results and to provide an operational overview. Post processing can provide detailed and/or statistically summarized results.

SLIDE 5

This formidible array of traffic is a typical example of the simulator's display of traffic being tracked within 10 nautical miles of own aircraft at 30 seconds into Scenario S-8 of the LAX simulation. In this particular situation there are 80 aircraft under track. 35 are ATCRBS equipped and 45 are Mode S equipped of which 25 are being tracked beyond the displayed area. The ATCRBS tracks are identified by triangles at the aircraft position while the Mode S tracks are identified by squares. The vector length and direction gives an indication of predicted motion for the next 25 seconds based on the past history of that target and own aircraft's current position and heading. A "Descend" command has been issued by the MITRE vertical separation CAS logic as the result of a conflict it has found with target #101. In this simulator own aircraft can be any of the 743 possible aircraft or any other aircraft at any location, altitude, altitude rate, heading or velocity one might choose to insert. The display used in this simulation is not intended to apply to an operational cockpit display. It seems clear that a pilot could not effectively use such a display.

SLIDE 6

Based on the previous example the simulation results are summarized in this viewgraph with the boundaries of the surveillance area as well as the protected area overlaid on the 10 NM range plot. The average density in this situation is 0.3 Aircraft per square Nautical Mile. It shows that all threats were detected and tracked and all intruders entering the protected space were located as required. It shows that the surveillance range of the actual hardware (including all hardware gains and losses) is adequate to provide an effective system.

It should be noted that no ATCRBS targets are being tracked outside of the surveillance volume while Mode S targets are being tracked out to 25 NM. This is the result of tailoring of the active resource of the system to the threat. Reply processing beyond the surveillance range is terminated except for Mode S where tracking is maintained to prevent repeated track initiation on squitter. The shape and extent of the 45 second protected volume within the surveillance volume takes into consideration own aircraft's speed and the maximum speed that other aircraft

can operate at that altitude according to Federal Air Regulations. The surveillance logic controls interrogations and reply processing so that ATCRBS targets operating at that velocity will be detected and a track established before they enter the CAS protected region.

Although no threats were missed during the performance simulations some targets were observed to enter the protected volume before being acquired due to the presence of intense synchronous garble. In this particular run three targets which are shown by asterisks at approximately 8 NM with bearings of 320 degrees, 358 degrees and 18 degrees penetrated the protected volume where the local traffic density is approximately 1 Aircraft per square Nautical Mile.

No false threats were declared on any of the many simulation runs. This is because the possibility of false tracking is virtually eliminated through the use of accurate angle information in the tracking process. Even in the situation where two targets crossed at identical positions (#598 and #549 located at 5.2 NM at a bearing of 160 degrees) the use of three dimensional position information permitted unambiguous tracking of each without any confusion.

The ability of the system to deal with pop-ups (a pop-up is a target which enters own coverage inside of the outer range limit, for example by climbing up from below) was demonstrated by turning on the Enhanced TCAS-II equipment in the midst of other targets. After starting the system with 79 ATCRBS targets at less than 10 NM and 55 Mode S targets at less than 25 NM, it successfully acquired targets within the surveiliance volume.

Threat Detection and Resolution was demonstrated as shown by the "Descend" command on the previous viewgraph. All of the Test scenarios currently stated in section 2.4 of the draft MOPS for TCAS II being prepared by RTCA SC 147 were also successfully handled by the simulated TCAS.

SLIDE 7

Prior to actually flying the Model A equipment the computer programs will be tested against the simulation test bed traffic and signal environment using the arrangement shown in this viewgraph. This capability offers several important benefits: it reduces flight test time and cost, permits stressful situations to be tested under controlled conditions and safely extends the scope of possible evaluation. It permits any special situations observed in real world flight testing to be duplicated in the laboratory and studied in much greater detail than is possible in actual flight. For example various "what if" conditions can be tried to optimize the system design.

SLIDE 8

As I mentioned earlier, Bendix considers the antenna the technological key to an operationally acceptable TCAS II. This is a photograph of the Engineering Model antenna which has been tested and is currently being integrated with other system components.

SLIDE 9

The Enhanced TCAS II antenna subsystem provides for time and pattern control of interrogation transmissions to constrain the interrogated sector to a fraction of the angle which we normally associate with a given antenna aperture. Using pictorial representations of the actual measured directional patterns, this viewgraph shows how the P1 and P3 pulses are transmitted on a sum beam while the P2 pulse is transmitted on a difference beam. ATCRBS equipped aircraft located within the effective beamwidth limits (shown by the dotted lines) would reply while those outside of this region would be suppressed.

SLIDE 10

The role of the Enhanced TCAS II antenna subsystem in the reception of replies is to measure the angle of arrival of the signal. This is accomplished using monopulse techniques within the effective angular region shown in this viewgraph. Replies as well as fruit arriving at angles outside of this sector are rejected using the receiver sidelobe suppression technique.

SLIDE 11

For the antenna experts present this strip chart shows actual measured patterns of the Enhanced TCAS II antenna subsystem.

SLIDE 12

The elements listed in this viewgraph all contribute to the Enhanced TCAS II systems horizontal resolution performance. Measured antenna patterns and measured circuit accuracy provide a factual basis. The Geometric Theory of Diffraction (GTD), which has been refined at Ohio State University, provides a computer model of the perturbations caused by reflection and diffraction of an airframe structure. Performance estimates derived from the use of these elements provide a basis for optimism. GTD error estimates will be checked during the actual flight tests by verifying system performance in the presence of airframe effects.

An Alpha-Beta tracker with its gain optimized to the rate at which the data is taken is used to predict future target position. When a particular target approaches the point where it is a threat, the minimum data rate is set at one measurement per second. Error contributions from all sources are statistically summed to obtain a three sigma error prediction.

SLIDE 13

When an aircraft is under track using the error elements just described, an estimate of the maneuver needed to assure a miss with 99 percent confidence is shown in this illustration.

SLIDE 14

It is shown that an acceleration of 15 feet per second per second produces a displacement equivalent to the three sigma error that results from an intruder closing at 1,000 Knots when he is 35 seconds from the closest point of approach.

SLIDE 15

This required acceleration is achieved at a bank angle of 25 degrees. Under these conditions the passenger feels a ten percent increase in seat weight. Such a maneuver can be made as the result of an early traffic advisory with no discomfort to the passenger (e.g. no coffee is spilled) and little or no effect on the ATC or aircraft control control systems.

SLIDE 16

I really do not expect you to read the printing on this block diagram of the Enhanced TCAS II Engineering Model System. However, it does indicate its eight subsystems. Directional antennas are installed on both the top and bottom of the 727 test aircraft. The interrogator is a modified production TRA-65 ATCRBS Transponder built by Bendix. The modification essentially inverts the operating frequencies. The Interrogator Processor has been specially designed to provide degarbling of up to four overlapped targets. A microprocessor within this unit controls the activities of the antenna, interrogator and signal processing units.

The computer executes the algorithms designed into the computer program and interfaces the system to the GFE displays, the monitor and controls and the Mode S transponder.

SLIDE 17

This drawing shows how the Engineering Model will be physically arranged in the 727 aircraft to facilitate the engineering test program. Commercial equipments were purchased wherever possible to minimize cost. The man-machine interface is facilitated by the various equipments provided which are spread over three racks in addition to the rack containing the basic equipment. In any subsequent production version of this system the the three aft racks of test equipment would be eliminated. The basic Enhanced TCAS II equipment shown on the first rack would be consolodated in a single ARINC standard package. The antenna steering circuitry would be integrally packaged with each antenna aperture and configured in a more suitable aerodynamic form.

SLIDE 18

In summary the benefits of the Enhanced TCAS II System include:

* A capability to resolve conflicts in the horizontal plane.

* The use of angular information to reduce unnecessary alerts.

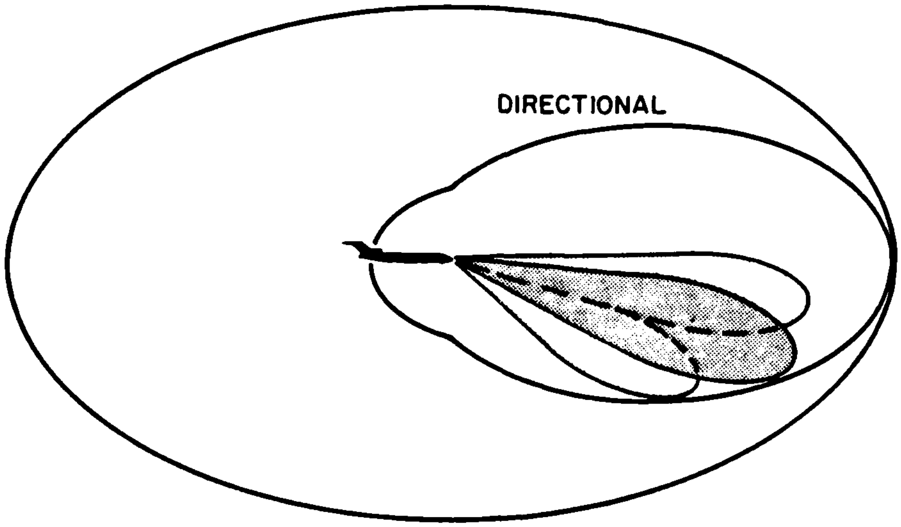
* Tracking accuracy capable of supporting the display of traffic advisories with relative motion that correlates with the pilots visual clues.

* Qualities which permit effective protection in high density traffic environments (sector interrogation, receive sidelobe suppression, degarbling, data filtering, high data corrolation accuracy, etc.).

* The ability to tailor parameters to minimize interference without loss of protection.

ENHANCEMENTS
(SLIDE 2)

FB-VG-819A



- HORIZONTAL RESOLUTION
- REDUCTION IN UNNECESSARY ALERTS
- TRAFFIC ADVISORIES WITH RELATIVE MOVEMENT
- RELATIVELY HIGH DENSITY OPERATION
- REDUCTION IN INTERFERENCE

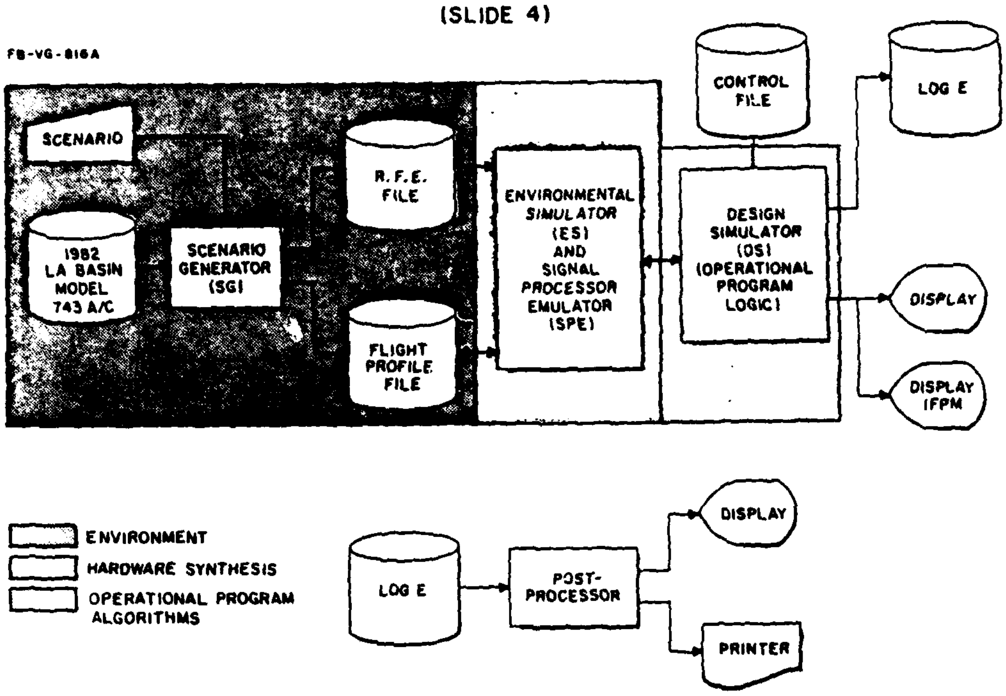
ENGINEERING ACHIEVEMENTS
(SLIDE 3)

FB-VG-820A

- CONCEPT - ENGINEERING MODEL DESIGN SPECIFICATION
- SIMULATION TEST BED - VALIDATE CONCEPT
- ACCURATE DIRECTIONAL ANTENNA
- MODEL A HARDWARE - NEAR COMPLETION

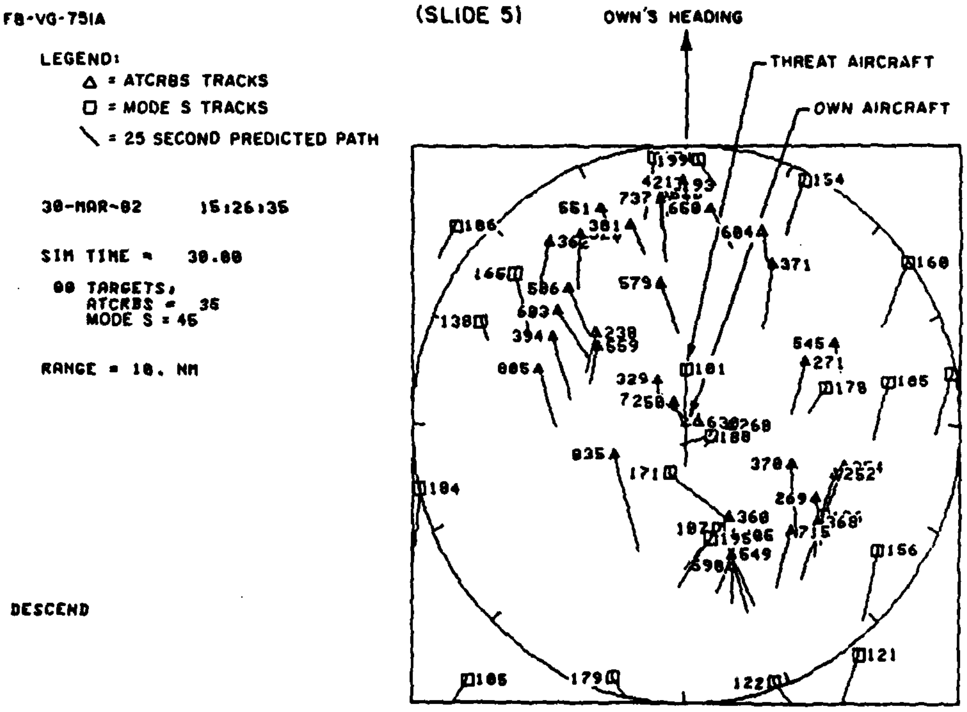
TCAS-II SIMULATION TEST BED CONFIGURATION
(SLIDE 4)

FB-VG-816A



SIMULATION TEST BED DISPLAY
TARGETS UNDER TRACK AT TIME = 30 SECONDS
(SLIDE 5)

FB-VG-751A

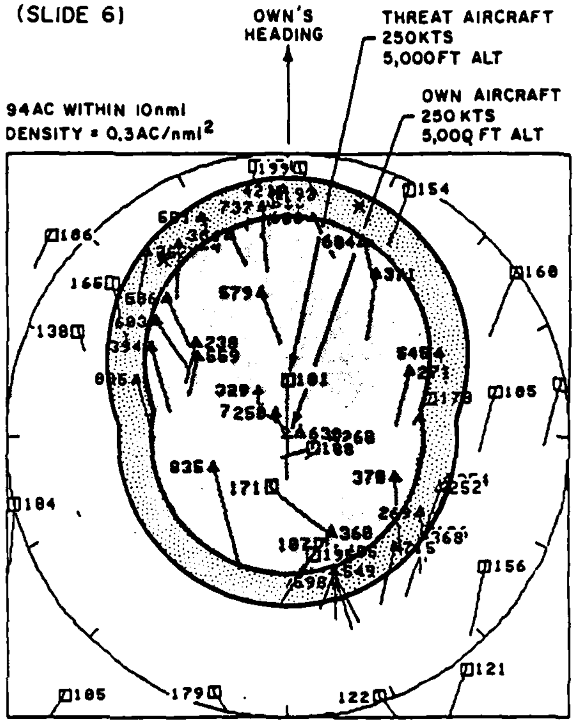


SIMULATION TEST RESULTS
TARGETS UNDER TRACK AT TIME = 30 SECONDS

FB-VG-614A

(SLIDE 6)

- DETECT & TRACK THREATS
- LOCATE INTRUDER
- SURVEILLANCE
- PROTECTED VOLUME
- MISSED THREATS
- FALSE THREATS
- POP UPS
- THREAT DETECTION & RESOLUTION



LEGEND:

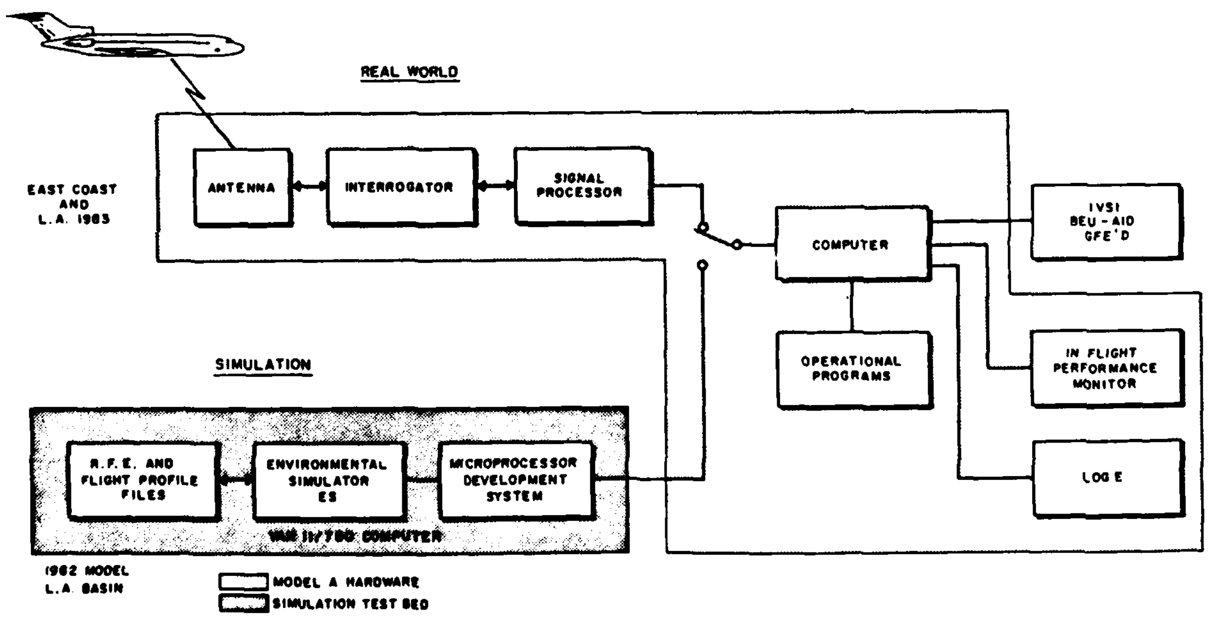
SURVEILLANCE COVERAGE

45 SECOND PROTECTIVE COVERAGE

TRANSITION FROM SIMULATION TO REAL WORLD

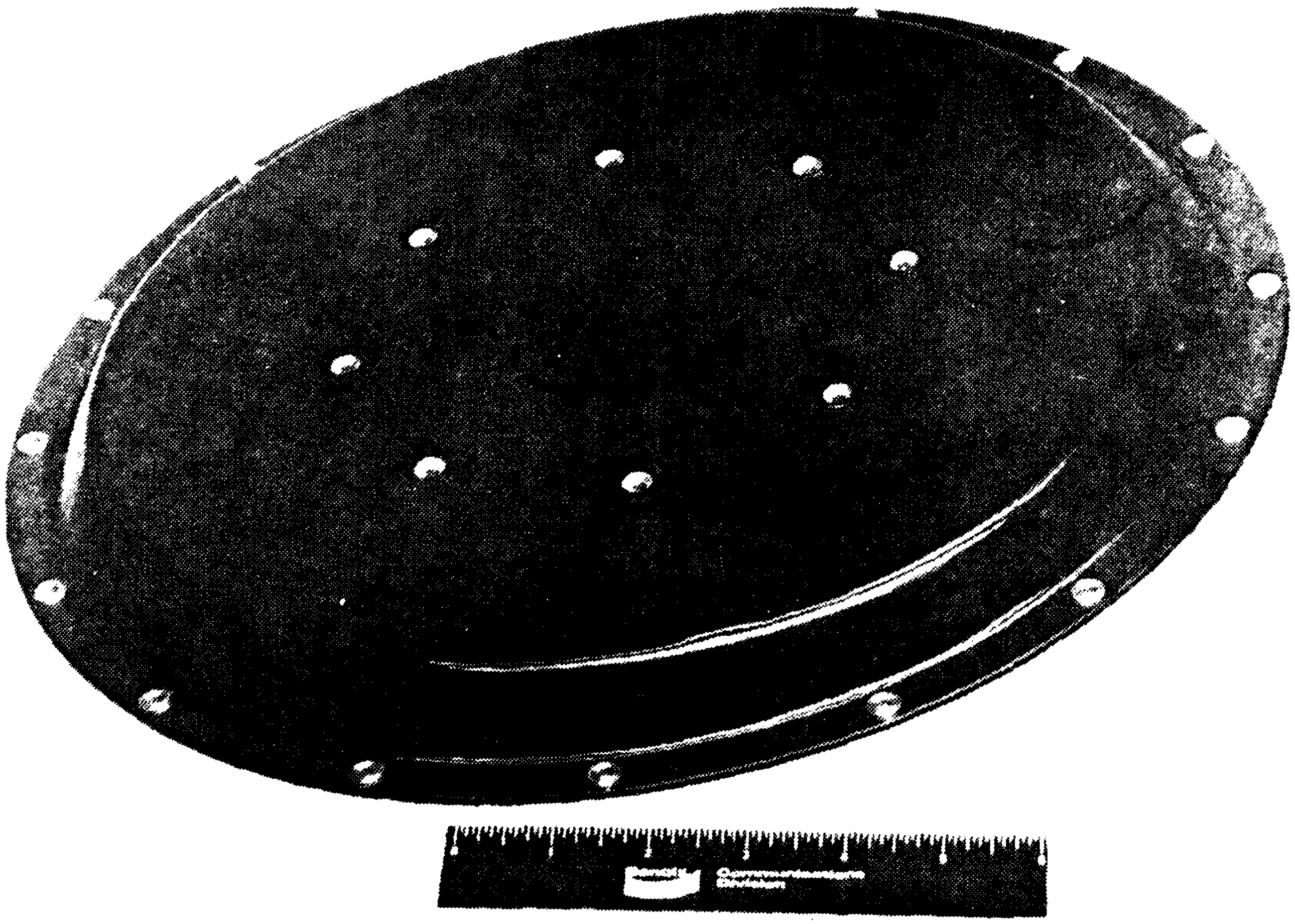
FB-VG-813A

(SLIDE 7)

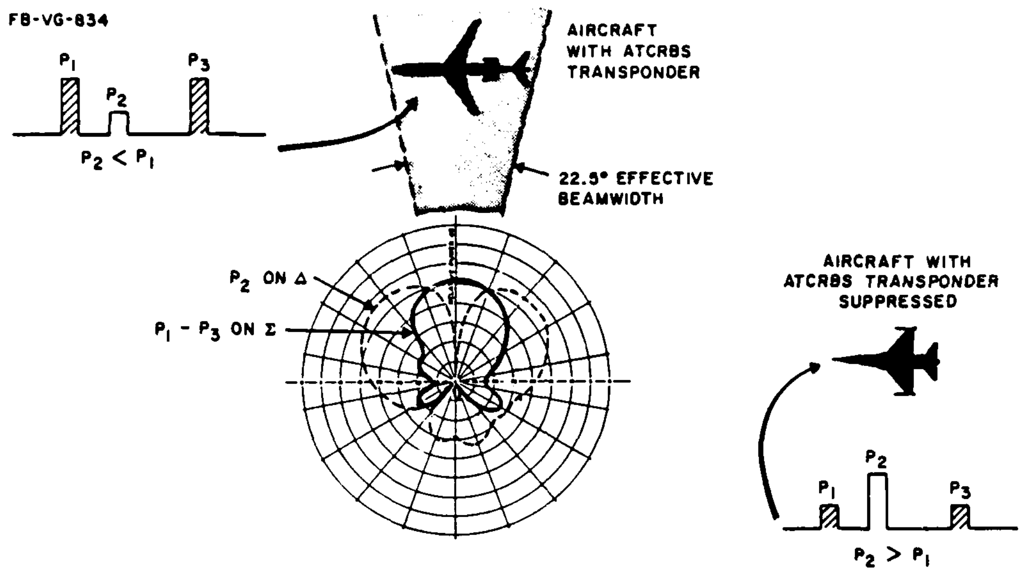


(SLIDE 8)

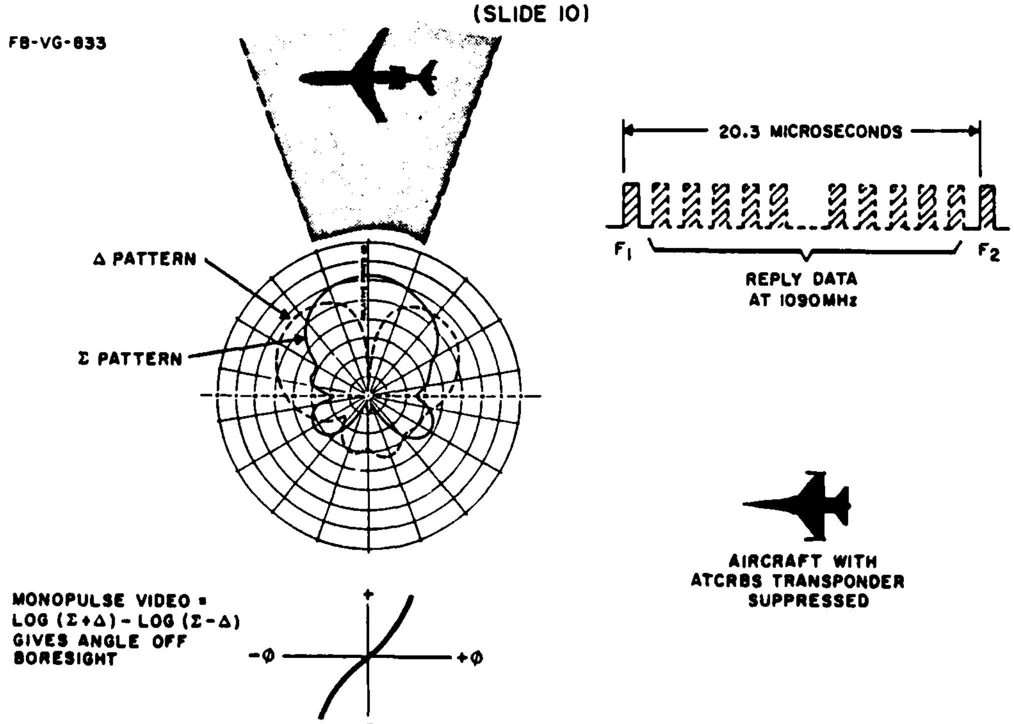
IRD 83-013



INTERROGATE MODE OF OPERATION
(SLIDE 9)

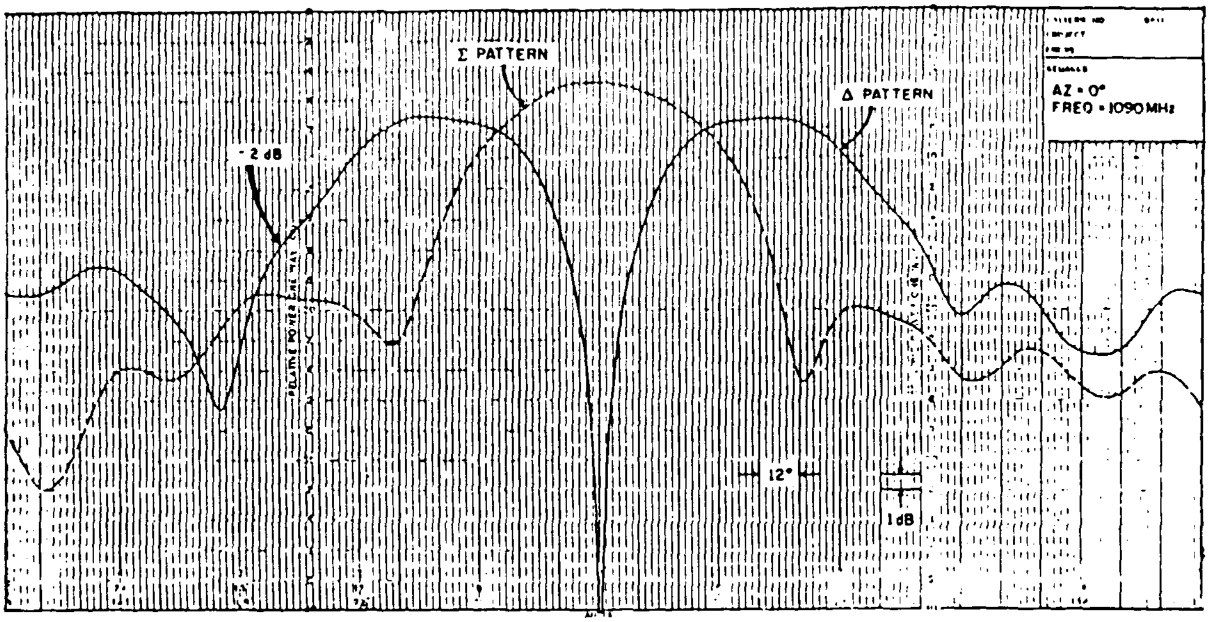


REPLY MODE OF OPERATION
(SLIDE 10)



ACTUAL TCAS ANTENNA PATTERNS
(SLIDE 11)

FB-VG-636A

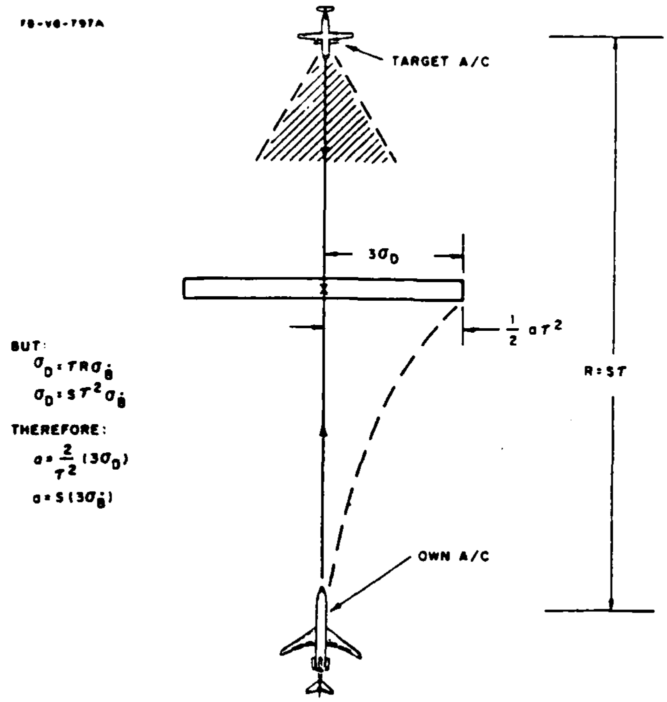


ELEMENTS OF PERFORMANCE ESTIMATE
(SLIDE 12)

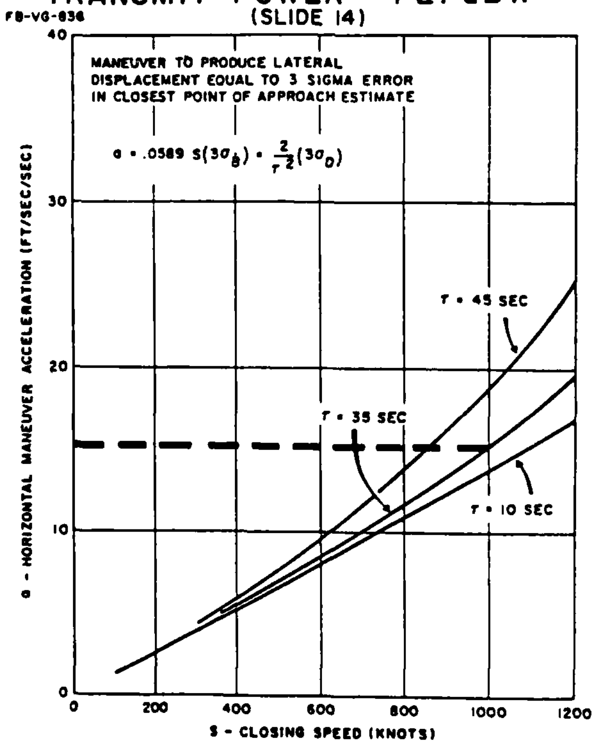
FB-VG-635

- MEASURED ANTENNA PATTERNS
- MEASURED CIRCUIT ACCURACIES
- GTD ESTIMATES OF AIRCRAFT STRUCTURE EFFECTS
- α/β TRACKER
- STATISTICAL ANALYSIS OF 3σ ERROR PREDICTION

HORIZONTAL MANEUVER TO MISS
(SLIDE 13)



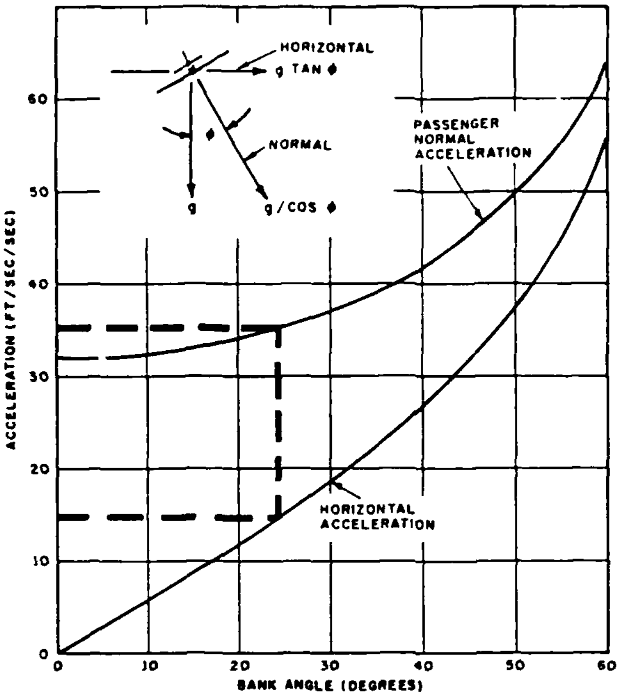
HORIZONTAL MANEUVER TO MISS TRANSPONDER TRANSMIT POWER = +27 dBW
(SLIDE 14)



HORIZONTAL MANEUVER ACCELERATION AS A FUNCTION OF BANK ANGLE

(SLIDE 15)

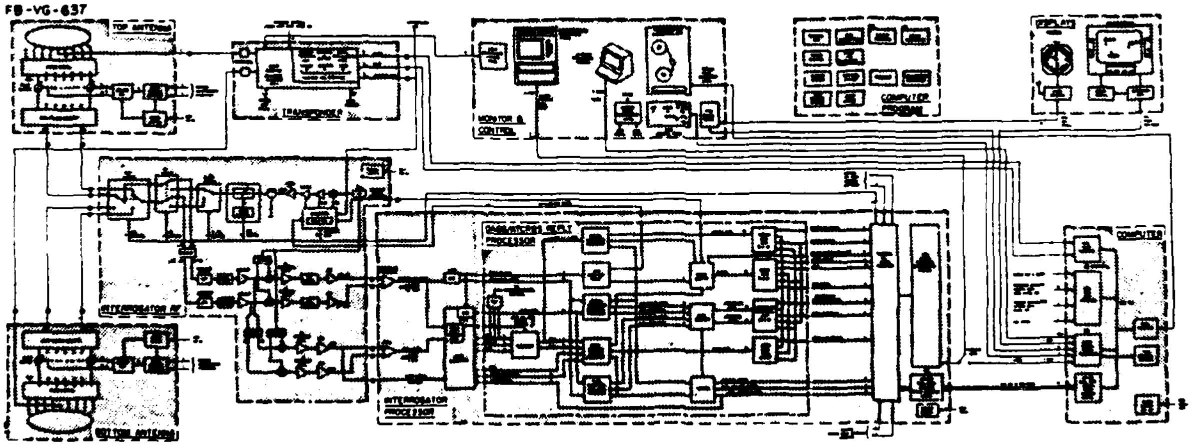
FB-VG-637



ENGINEERING MODEL SYSTEM BLOCK DIAGRAM

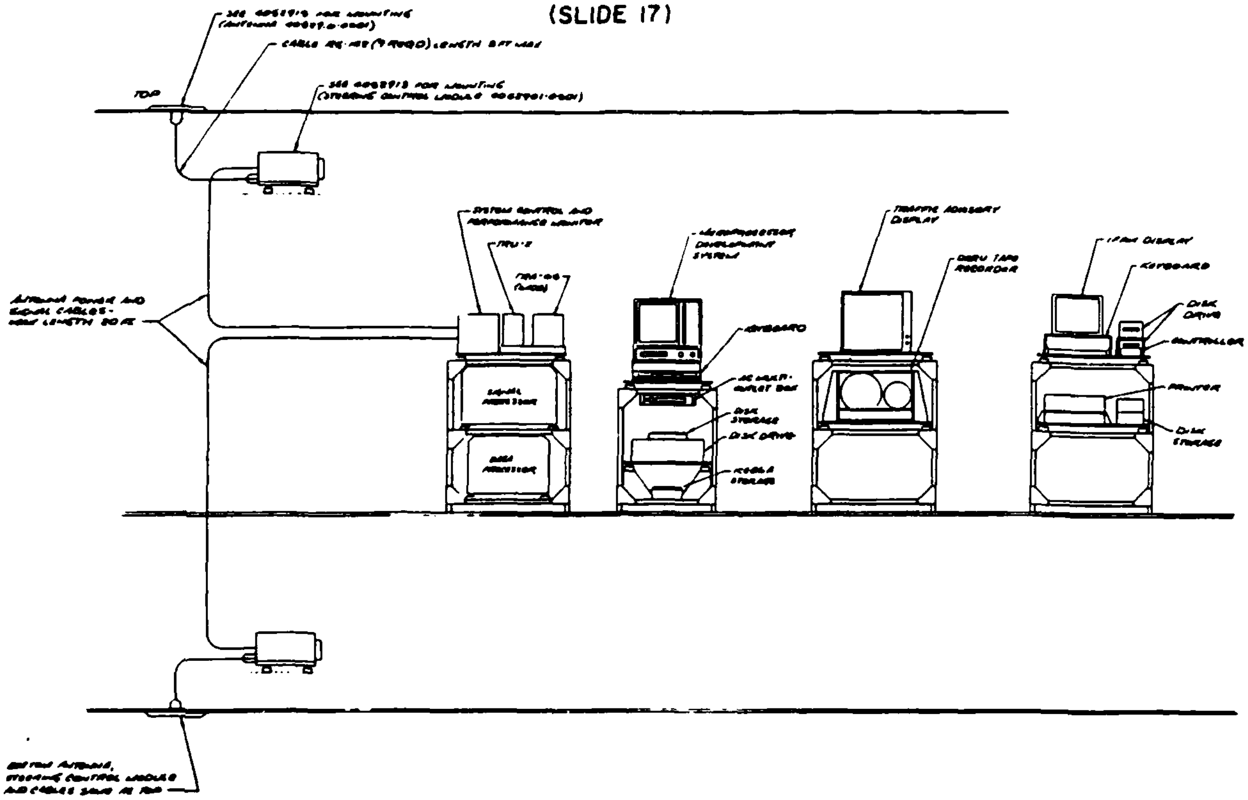
(SLIDE 16)

FB-VG-637



TCAS-II ENGINEERING MODEL INSTALLATION
FLYING TEST BED
(SLIDE 17)

FB-VG-719



ADVANTAGES OF ACCURATE DIRECTIONAL DESIGN
(SLIDE 18)

FB-VG-827A

- HORIZONTAL RESOLUTION
- REDUCES UNNECESSARY ALERTS
- TRAFFIC ADVISORIES WITH RELATIVE MOVEMENT
- RELATIVELY HIGH DENSITY OPERATION
- REDUCES INTERFERENCE

MINIMUM TCAS II THREAT DETECTION AND RESOLUTION LOGIC STATUS

ANDREW ZEITLIN
MITRE CORPORATION
OCTOBER 12, 1982

INTRODUCTION

THIS TALK UPDATES THE STATUS REPORT GIVEN AT JANUARY, 1982 SYMPOSIUM

LOGIC HAS BEEN REFINED AS RESULT OF OPERATIONAL AND SIMULATION TESTING

- SOLVED PROBLEMS OBSERVED IN SIMULATION OR FLIGHT TESTING
- FEWER PROBLEMS WERE SEEN WITH EACH REVISION. NONE REMAINING
- RESPONDED TO REQUESTS FOR IMPROVED FEATURES

COMPLETE LOGIC SPECIFICATION BEING PUBLISHED FOR USE WITH MOPS OF RTCA SC-147

INTRODUCTION

The purpose of this talk is to give a status update on the Collision Avoidance Logic for Minimum TCAS II. At the January, 1982 TCAS Symposium, a progress report was given, which included problems and limitations of the logic. The process of refinement has continued, using data from flight tests and simulations. All problems that have been observed have now been solved. Also, improved features have been added. The entire process has been performed in close cooperation with the FAA and RTCA SC-147.

The resulting logic is about to be published in a report, which will be incorporated in SC-147's Minimum Operational Performance Standard. Most of this talk today covers new developments and features in the logic. Validation activities are also briefly described.

LOGIC CHANGES MADE SINCE JANUARY 1982 SYMPOSIUM

TRACKING

REFINEMENTS TO LOGIC USED TO TRACK INTRUDER'S MODE-C ALTITUDE.

THERE ARE VARIOUS SITUATIONS WHERE VERTICAL RATE IS UNCLEAR OR MAY BE CHANGING.

BASIC APPROACH:

1. RECOGNIZE THESE SITUATIONS - "KNOW WHEN WE DON'T KNOW" THE RATE.
2. DEFER (UP/DOWN) SENSE AND ADVISORY SELECTION UNTIL SITUATION CLEARS UP.

IMPROVED APPROACH:

1. CONSTANTLY ESTIMATE THE MAXIMUM AND MINIMUM RATE THAT COULD BE CONSISTENT WITH THE OBSERVED DATA.
2. IF A MANEUVER CHOICE IS SATISFACTORY FOR THE ENTIRE RANGE OF UNCERTAINTY, SELECT IT WITHOUT DELAY.
3. OTHERWISE, DEFER SELECTION UNTIL RATE IS KNOWN WITH CERTAINTY OR (2) APPLIES.

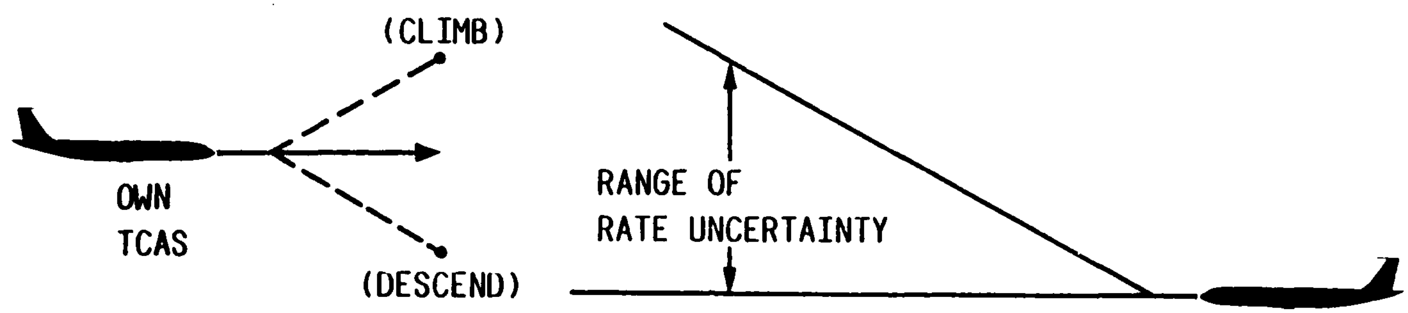
TRACKING INTRUDER ALTITUDE

Many of the problems previously observed in the logic were due to erroneous tracking of intruder's vertical rate. This is important because the logic selects its escape maneuver while there is still time to escape. Thus, it projects intruder altitude ahead in time using its rate estimate.

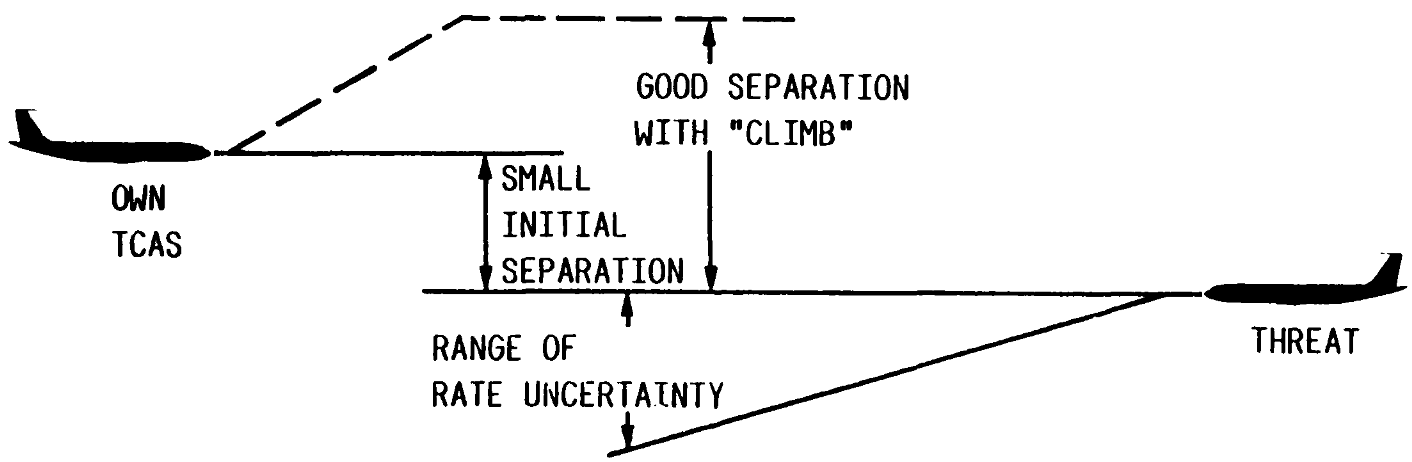
The source of tracking errors is the 100-foot quantization of altitude reports received from intruder's transponder. If intruder maintains a constant rate, his rate can be tracked accurately after some time. However, if intruder changes rate, it again takes some time before the sequence of reports portrays the new rate. During this period, the logic is vulnerable to error.

A great deal of work has gone into logic which recognizes when a sequence of reports implies some uncertainty in the rate estimate. On the simplest level, then, decisions are deferred when there is low confidence in the rate. The uncertainty is usually cleared up after a few more reports, and a decision can be safely made. The approach was improved by continually estimating upper and lower limits of rate uncertainty and recognizing that in some situations a maneuver may be expected to be successful regardless of how large the uncertainty.

SENSE CHOICE WITH VERTICAL RATE UNCERTAINTY



EXAMPLE 1:
MUST DELAY CHOICE



EXAMPLE 2:
THREAT MAY BE LEVEL OR DESCENDING, BUT "CLIMB" WILL WORK

TRACKING OWN ALTITUDE

THE LOGIC ALLOWS TCAS TO SUPPLY EITHER FINELY QUANTIZED ALTITUDE (E.G. AIR DATA COMPUTER) OR MODE-C ALTITUDE FOR OWN-SHIP.

APPROPRIATE TRACKING IS USED ACCORDING TO THE SOURCE SELECTED.

- FINE ALTITUDE TRACKED WITH ALPHA-BETA SMOOTHING
- MODE-C TRACKED LIKE INTRUDERS

FINELY QUANTIZED ALTITUDE IS PREFERRED BECAUSE RATE TRACKING ERRORS ARE MUCH LOWER.

CONFLICT DETECTION

AVOID UNWANTED ALERTS WHEN CONFLICT GEOMETRY HAS LARGE HORIZONTAL MISS DISTANCE

USE DERIVATIVE OF CALCULATED TAU ("TAU-DOT")

RANGE DATA COLLECTED TO DATE HAS BEEN OF ACCURACY SUFFICIENT TO SUPPORT THIS FEATURE

ADVISORY SELECTION

1. MORE GENERALIZED USE OF MODELING

2. KEEP POSITIVE ADVISORY ON UNTIL VERTICAL SEPARATION ACHIEVED (DON'T TURN OFF ON PROJECTED SEPARATION)

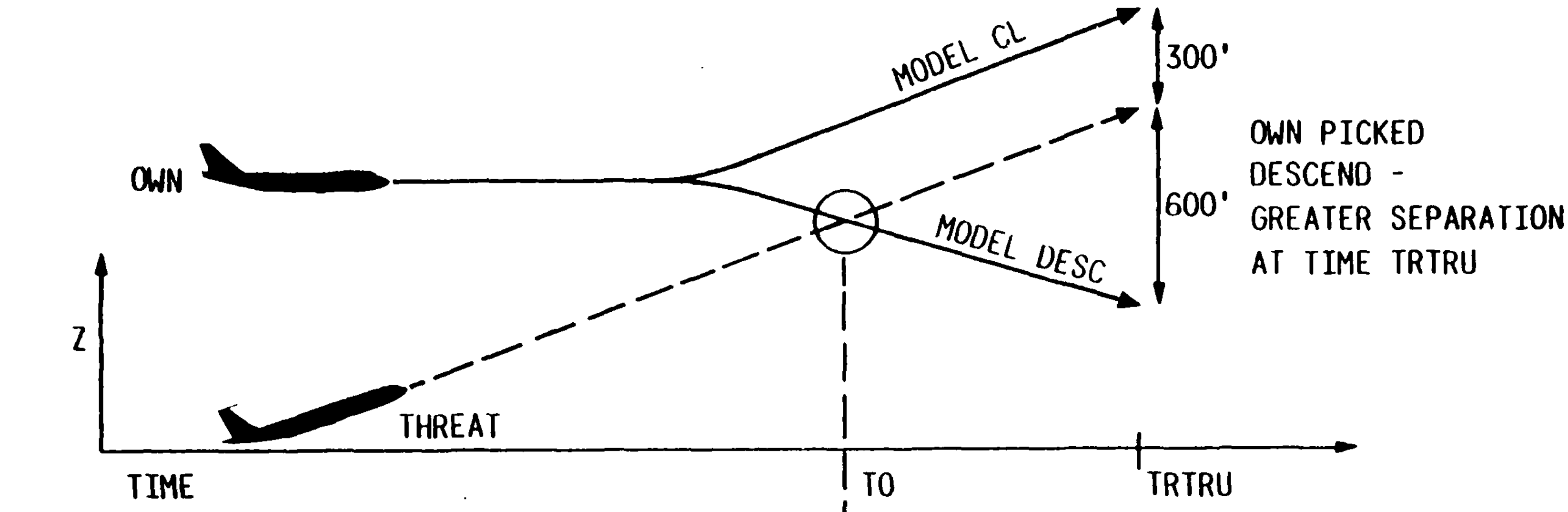
3. DON'T ANTICIPATE HELP FROM A TCAS-EQUIPPED THREAT - HE MAY NOT DETECT THE CONFLICT

4. TCAS-EQUIPPED AIRCRAFT ALWAYS CHOOSE COMPATIBLE MANEUVERS WHEN THEY BOTH DETECT CONFLICT

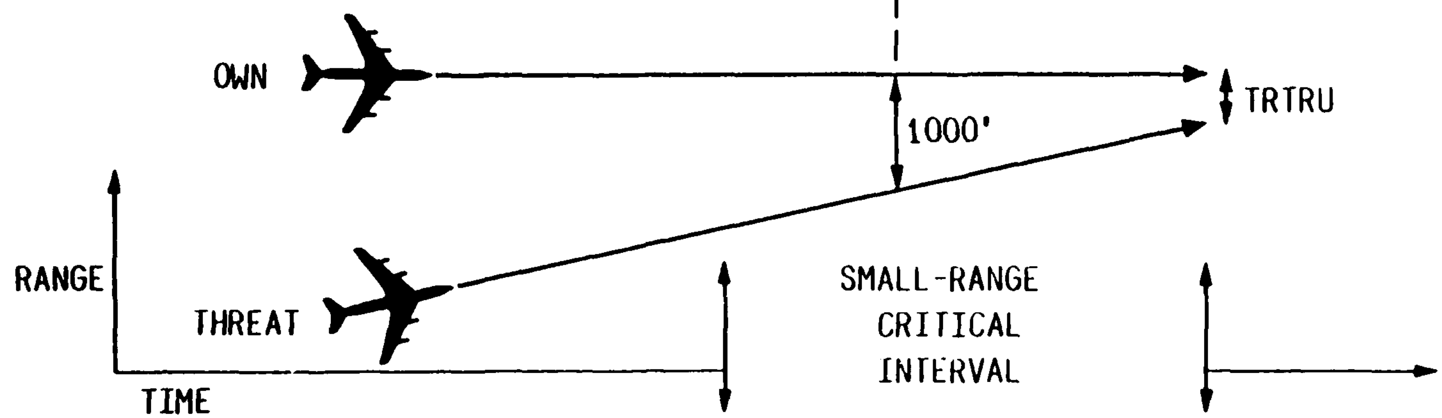
5. SPECIAL DETECTION AND MODELING METHOD FOR TAIL-CHASE GEOMETRIES

    - MODEL OVER A CRITICAL RANGE
    - FOR NORMAL GEOMETRIES, THIS RANGE COLLAPSES INTO SINGLE POINT, SAME AS STANDARD LOGIC

MODELING FOR TAILCHASE GEOMETRIES



HOWEVER, WELL BEFORE CPA, AIRCRAFT ARE COALTITUDE WITH NEGLIGIBLE RANGE. (TIME TO)



NEW MODEL PICKS SENSE WHOSE MINIMUM SEPARATION OVER CRITICAL INTERVAL IS MAXIMUM.

AIRCRAFT PERFORMANCE INTERFACE

IN SOME SITUATIONS, AIRCRAFT MAY NOT BE ABLE TO PERFORM ADEQUATE CLIMB ESCAPE MANEUVER.

TCAS LOGIC PROVIDES INTERFACE FOR A "CAN'T CLIMB" DETERMINATION UNIQUE TO AIRCRAFT TYPE. THIS MIGHT INCLUDE TEMPERATURE, AIRSPEED, WEIGHT, AND/OR ALTITUDE, AT CRUISE ALTITUDE, AND FLAP/GEAR SETTINGS AT LOW ALTITUDE.

- DETAILS ARE LEFT TO AIRCRAFT MANUFACTURER
- FOR FAA TEST PROGRAM, WILL USE FIXED ALTITUDE FOR CRUISE-ALTITUDE LIMIT, FLAP/GEAR DOWN FOR LANDING CONFIGURATION.

WHEN AIRCRAFT CAN'T CLIMB, TCAS COMPARES LEVEL VS DESCEND AND MAKES BEST CHOICE.

ADVISORY EVALUATION LOGIC

WHAT SHOULD TCAS DO IF AN ADVISORY IS LATER SEEN TO BE NOT WORKING?

FUNCTION: WARN THAT AN ADVISORY NO LONGER APPLIES IF IT BECOMES THE "WRONG DIRECTION."

CAUSES:

A. CLASSICAL "FAKE-OUT" MANEUVER WHERE THREAT CHANGES COURSE AND FOILS TCAS CHOICE.

B. PILOT DELAYS SO LONG THAT ORIGINAL ADVISORY IS NOT VALID.

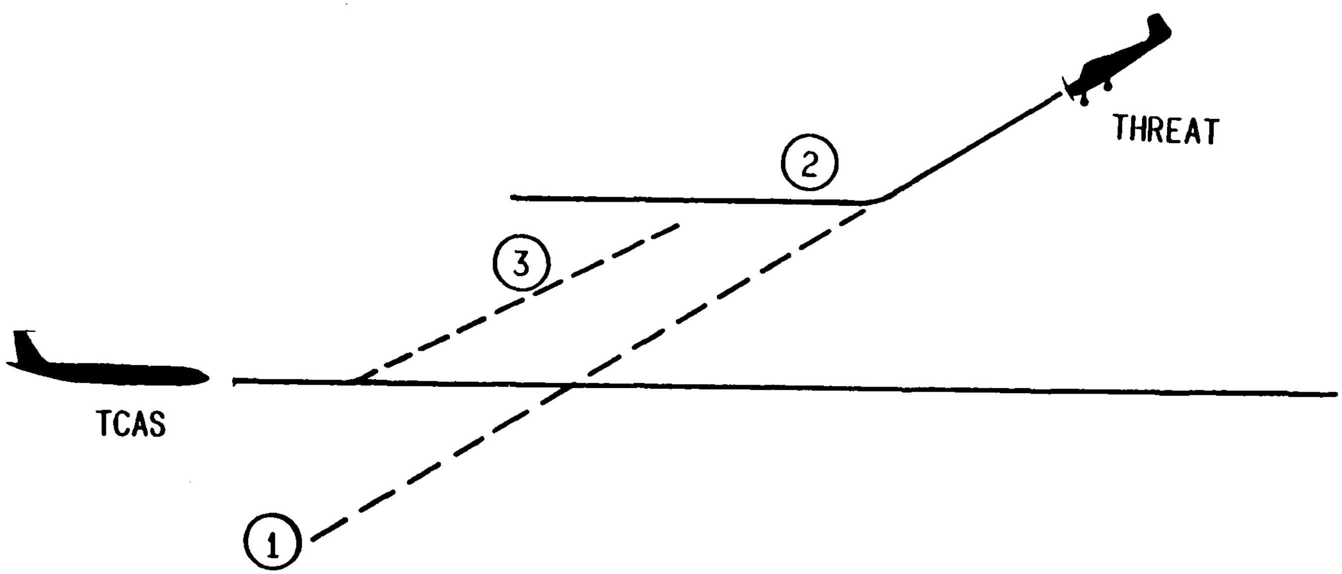
C. VERY LATE ALARM (POP-UP, SEVERE ACCELERATION, OR VERTICAL TRACKER UNCERTAINTY) AND "BEST" MANEUVER IS NOT ADEQUATE.

LOGIC DETAILS:

- EVALUATE POSITIVE ADVISORY WHEN FIRST SELECTED, AND AGAIN EACH SCAN AFTER IT IS DISPLAYED (EXCEPT WHEN UNSURE OF VERTICAL RATE).
- IF TCAS, BY IMMEDIATELY FOLLOWING THE DISPLAYED ADVISORY, WOULD ACHIEVE LESS THAN 100 FT SEPARATION IN THE CHOSEN DIRECTION, DECLARE ADVISORY NOT-OK.
- NOT-OK INDICATION STAYS ON UNTIL END OF ENCOUNTER.
- TRAFFIC ADVISORY STAYS ON.

WHEN NOT-OK INDICATION APPEARS, PILOT SHOULD IGNORE ORIGINAL RESOLUTION ADVISORY AND USE ALL AVAILABLE SOURCES OF INFORMATION.

ADVISORY EVALUATION LOGIC



1. THREAT INITIALLY PROJECTED TO CROSS BELOW. TCAS SELECTS "CLIMB".
2. THREAT THEN LEVELS OFF. "CLIMB" BECOMES WRONG THING TO DO.
3. ADVISORY EVALUATION LOGIC REMOVES "CLIMB" AND ALERTS PILOT THAT TCAS CANNOT RESOLVE ENCOUNTER.

RESOLUTION ADVISORY OUTPUTS

REQUIRED:

CLIMB	DESCEND
DON'T DESCEND	DON'T CLIMB
LIMIT DESCENT 500 FPM	LIMIT CLIMB 500
LIMIT DESCENT 1000 FPM	LIMIT CLIMB 1000
LIMIT DESCENT 2000 FPM	LIMIT CLIMB 2000

ADVISORY NOT-OK
AURAL ALERT

OTHER OUTPUTS: (OPTIONAL)

CORRECTIVE (CHANGE IN FLIGHT PATH REQUIRED)
PREVENTIVE (CHANGE NOT REQUIRED)
MAINTAIN RATE (WHEN POSITIVE NEEDED BUT EXISTING RATE OK)
VERTICAL RATE MODELED - FOR POSITIVE (SHOWS RATE TO MAINTAIN)

DELAY DUE TO RATE UNCERTAINTY

RULE FOR (MINIMUM) AURAL ALERT:

1. FIRST RA AGAINST THREAT.

OR 2. ANY CORRECTIVE RA CHANGES SEVERITY.

OR 3. PREVENTIVE RA BECOMES CORRECTIVE.

NOTE: AURAL ALERT MAY BE GIVEN MORE OFTEN
(E. G. EVERY CHANGE OF SEVERITY)

TRAFFIC ADVISORY LOGIC

TRAFFIC ADVISORY INTENDED TO AID LOCATION OF TRAFFIC AND WARN OF IMPENDING RA. TYPICALLY 15 SECONDS LATER.

TA IS OPTIONAL. TYPICALLY CONTAINS RANGE, ALTITUDE, BEARING, ALTITUDE RATE. CAN CONTAIN ANY OTHER DATA KNOWN TO CAS LOGIC.

ALL PROXIMATE TRAFFIC WITHIN 2 NMI RANGE, 1200 FT ALTITUDE GIVEN WHEN RA OR TA IS ACTIVE, TO AVOID CONFUSION OF THREAT CAUSING ADVISORY.

NON-MODE-C INTRUDERS ARE INCLUDED IN TA LOGIC ALTHOUGH ALTITUDE IS UNKNOWN. THESE ARE NOT DISPLAYED WHEN OWN TCAS IS OPERATING WELL ABOVE, 12000 FT ALTITUDE, BELOW WHICH MODE-C IS REQUIRED.

IF DISPLAY HAS LIMITED CAPACITY FOR TA'S, A PRIORITY RANKING SHOWS WHICH TO DISPLAY.

1. THREAT(S) CAUSING RA.
2. REGULAR TA'S, BOTH MODE-C AND NON-MODE-C.

   A. VERY CLOSE RANGE, BY RANGE
   B. OTHER CONVERGING, BY RANGE TAU
   C. OTHER, BY RANGE

3. PROXIMATE TRAFFIC, BOTH MODE-C AND NON-MODE-C, BY RANGE.

RESOLUTION ADVISORY OUTPUTS

REQUIRED:

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	DON'T DESCEND	DON'T CLIMB
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	LIMIT DESCENT 1000 FPM	LIMIT CLIMB 1000
	LIMIT DESCENT 2000 FPM	LIMIT CLIMB 2000

ADVISORY NOT-OK
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DESENSITIZATION

PIEDMONT FLIGHTS CONFIRMED EARLIER STUDIES. SHOWED THAT RADAR ALTIMETER METHOD WORKED WELL. EXCEPT FOR AIRCRAFT ON GROUND.

NEW LOGIC TO ELIMINATE THREATS ON GROUND REQUIRES CONTINUOUS RADAR ALTIMETER INPUT.

- THIS INPUT DOES NOT NEED TO BE TRACKED
- LOGIC USES HYSTERESIS AND CREDIBILITY TEST

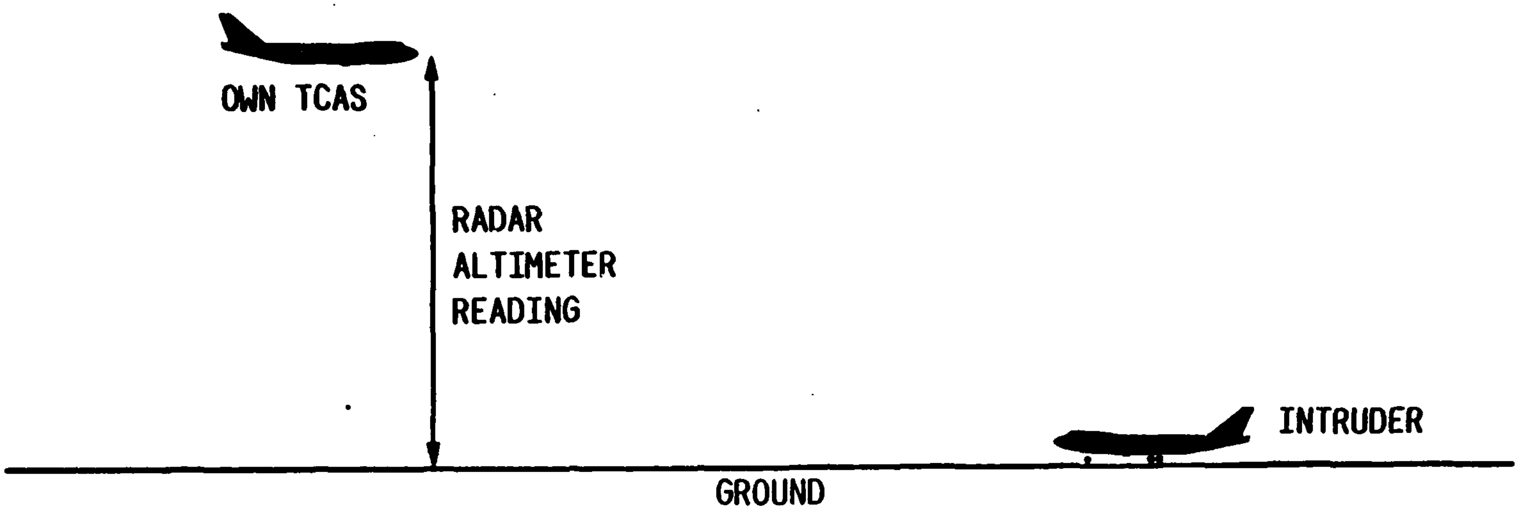
SENSITIVITY LEVEL SET BY:

RADAR AND BAROMETRIC ALTITUDE

MANUAL SWITCH (OPTIONAL) MAY LOWER SL FROM THAT SELECTED BY ALTITUDE

MESSAGE FROM GROUND-BASED MODE-S SENSOR (OPTIONAL) CAN IMPLEMENT DESENSITIZATION MAP IN SPECIAL AREAS

ELIMINATING INTRUDERS ON THE GROUND



1. SUBTRACT RADAR ALTITUDE FROM OWN BAROMETRIC ALTITUDE TO FIND ALTITUDE REPORTED BY INTRUDERS ON THE GROUND.

2. ADD 180 FT TO THE ESTIMATE TO ACCOUNT FOR ALTIMETRY ERROR, SLOPING TERRAIN, ETC.

3. IF INTRUDER IS BELOW THIS ALTITUDE, DO NOT ALERT.

4. DO NOT MAKE ESTIMATE IF OWN TCAS IS HIGH (I.E. ABOVE 900 FT), OR IF RADAR ALTITUDE DATA HAS NOT BEEN AVAILABLE FOR A LONG TIME. THEN ALL INTRUDERS ARE CONSIDERED "IN THE AIR" AND VALID.

SENSITIVITY LEVELS

LARGEST ALIM

29,000 FT MSL

LARGE ALIM

LEVEL 6
(TAU=30)

18,000 FT MSL

MODERATE ALIM

10,000 FT MSL

LOWEST ALIM

LEVEL 5
(TAU=25)

2,500 FT AGL

LEVEL 4
(TAU=20)

500 FT AGL

LEVEL 2
(NO RESOLUTION ADVISORIES)

GROUND LEVEL

VERIFICATION ACTIVITIES AT MITRE

SIMULATION USING DATA BASE OF ENCOUNTER SCENARIOS DESIGNED TO STRESS LOGIC

REPLAY THROUGH HISTORICAL ENCOUNTERS:

- RECORDED PIEDMONT FLIGHTS
- PLANNED ENCOUNTERS AT FAA TECH CENTER
- PLANNED ENCOUNTERS AT LINCOLN LAB
- ACTUAL MIDAIR COLLISIONS
- ARTS DATA FROM HOUSTON

THIS DATA HAS BEEN USED TO VALIDATE LOGIC CHANGES. MITRE IS IN THE MIDST OF AN EXHAUSTIVE VALIDATION ACTIVITY OF THE COMPLETE LOGIC.

STATUS

LOGIC FELT TO BE QUITE MATURE, RELIABLE

REPORT CONTAINING COMPLETE ALGORITHM SPECIFICATION AND EXPLANATION. DRAFT HAS BEEN COMPLETED, SOON AVAILABLE TO RTCA SC-147

ENHANCED TCAS LOGIC:

- WORK BEGINNING ON LOGIC TO GENERATE HORIZONTAL AND VERTICAL MANEUVERS
- DELIVERY OF A FIRST, SIMPLE LOGIC SCHEDULED FOR JANUARY FOR USE WITH TEST FLIGHTS OF BENDIX EQUIPMENT

TCAS II THREAT DETECTION

AND RESOLUTION LOGIC

TESTING

FAA TECHNICAL CENTER

ATLANTIC CITY, N.J. 08405

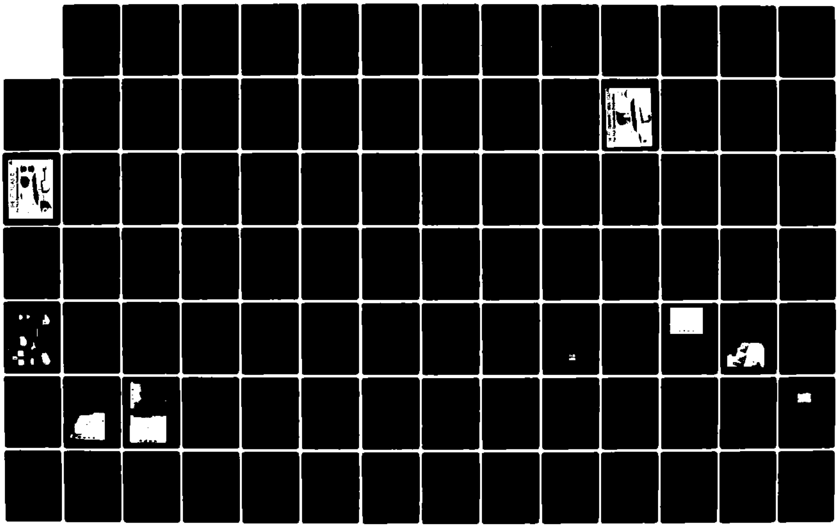
TECHNICAL PROGRAM MANAGER

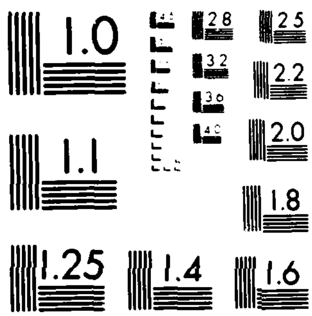
BARRY R. BILLMANN, ACT-220

OCTOBER 12, 1982

AD-A123 037 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) 3/4
SYMPOSIUM (3RD) OCTOBER 12-13 1982(U) FEDERAL AVIATION
ADMINISTRATION WASHINGTON DC SYSTEMS RESEARC.. 1982

UNCLASSIFIED DOT/FAA/RD-82/75 F/G 17/7 NL





MICROCOPY RESOLUTION TEST CHART

OBJECTIVES

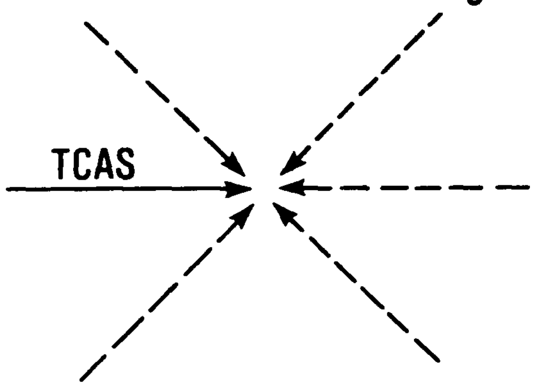
- EVALUATE TCAS THREAT DETECTION AND RESOLUTION LOGIC PERFORMANCE
- VERIFY THREAT LOGIC IMPLEMENTATION IN TCAS HARDWARE
- IDENTIFY LOGIC IMPROVEMENTS/REFINEMENTS

LOGIC TESTING ACTIVITIES

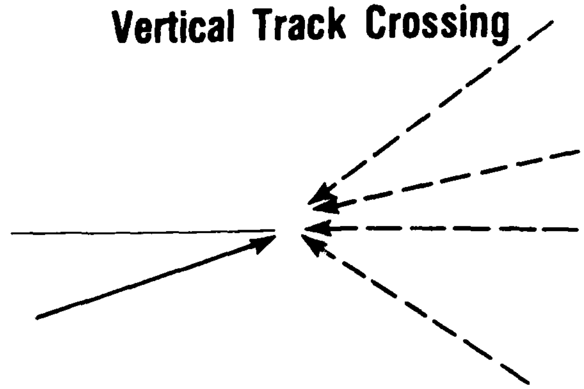
- SIMULATION TESTING
  - FAST TIME ENCOUNTER GENERATOR
- CAPABILITIES
  - RAPID SCENARIO MODIFICATION/REPLICATION OVER WIDE RANGE OF CONDITIONS
  - MODELS MULTIPLE INTRUDERS
  - EXPLICIT MODELING OF SURVEILLANCE AND COORDINATION INTERFACES
  - PILOT AND AIRCRAFT RESPONSES ACCURATELY MODELED
- PHASED EVALUATION CONCEPT
  - UNEQUIPPED (ATCRBS MODE C) INTRUDERS
  - TCAS EQUIPPED INTRUDERS
  - MULTIPLE INTRUDERS WITH VARIOUS EQUIPMENT COMBINATIONS

Example of Testing Depth

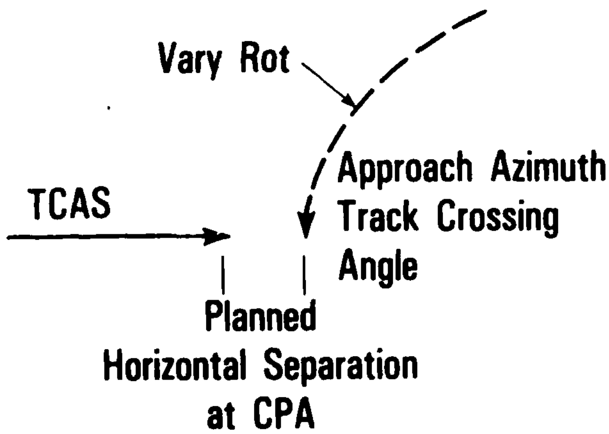
Horizontal Track Crossing



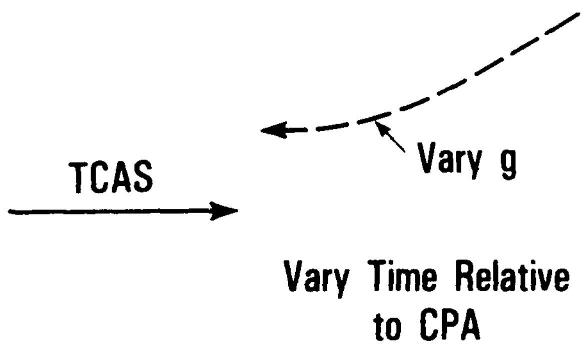
Vertical Track Crossing



Horizontal Maneuvering



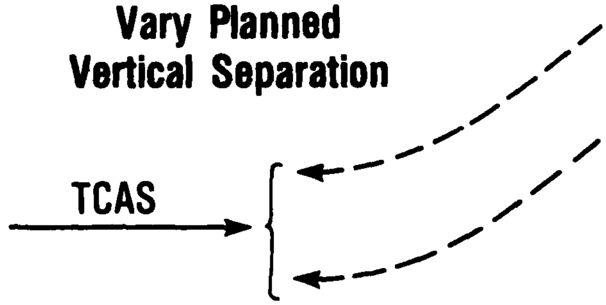
Vertical Maneuvering

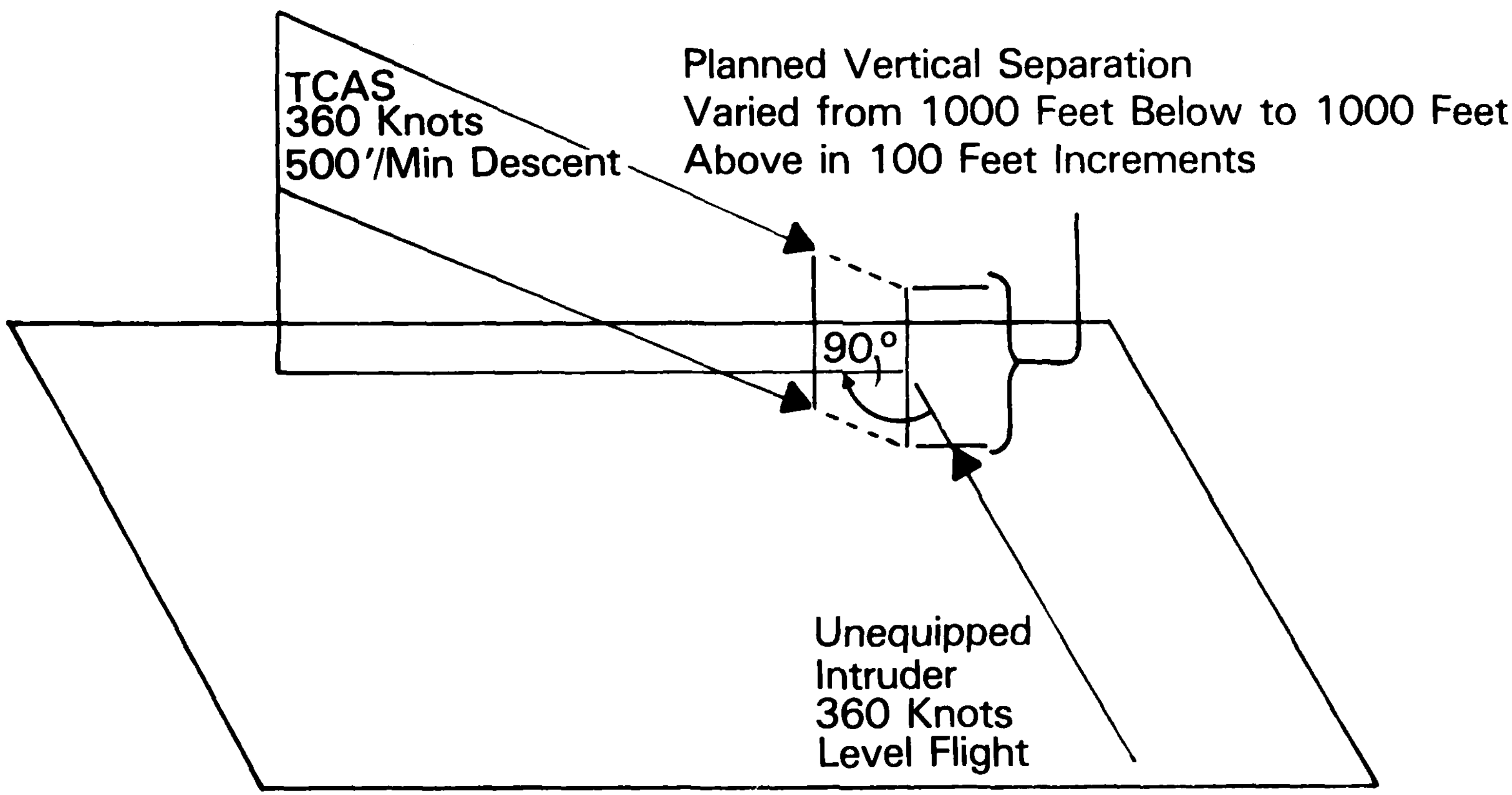


Additional Controls:

- Pilot Response Delay
- Aircraft Response Rate
- % of Surveillance Replies Passed to Threat Logic

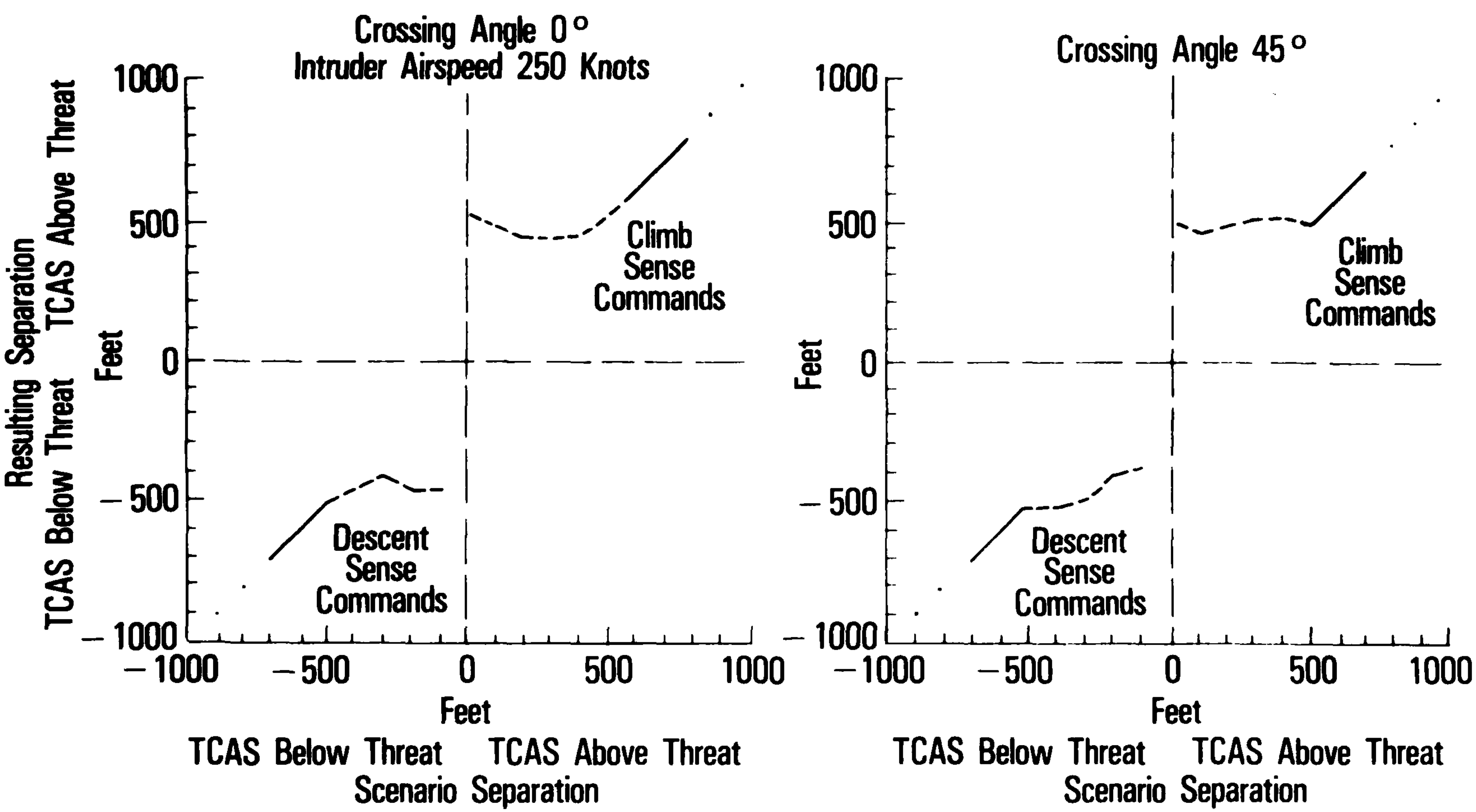
Vary Planned Vertical Separation





Example of Use of Preprocessor to Incrementally Modify Scenarios

Level 5 Parameter Settings



Level Flight Scenario Results (Low Crossing Angles)

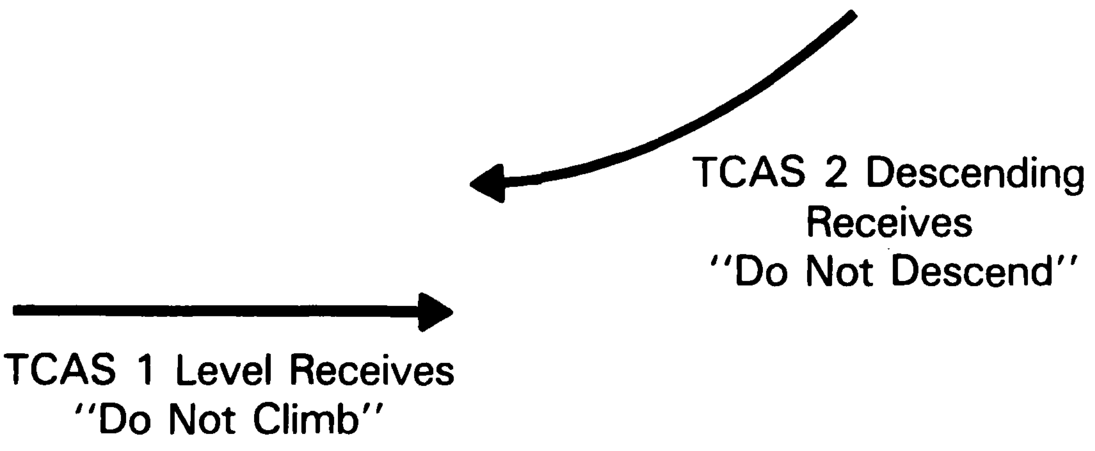
Case Study 1: Impact of Equal Treatment for TCAS Intruders

Previous Logic - 2 Negative Commands Would Generate Sufficient Separation

- Positive Command Only if Both Current and Projected Vertical Separation is Less Than 440 Feet
- Prevented Excessive Vertical Maneuvering

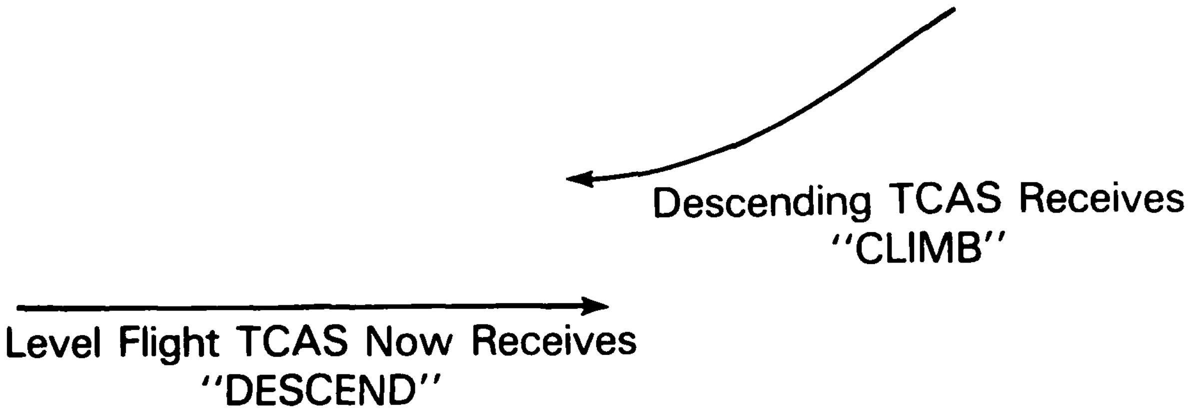
Possible Problem With Late or No Response

New Logic - If Projected Separation is Less Than 440 Feet, Positive Command Regardless of Equippage

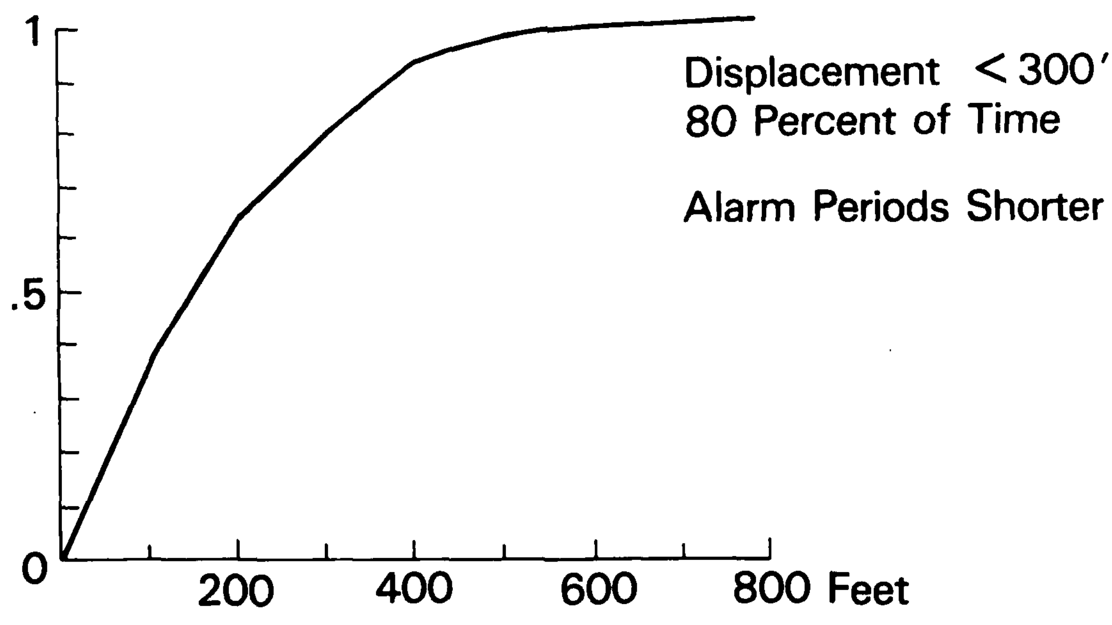


Question: What is Magnitude of Induced Vertical Displacement of Level Flight TCAS?

Case Study 1



Results for 521 Encounters - High Altitude Parameters



Probability Vertical Displacement Exceeds X Feet

Surveillance Playback System

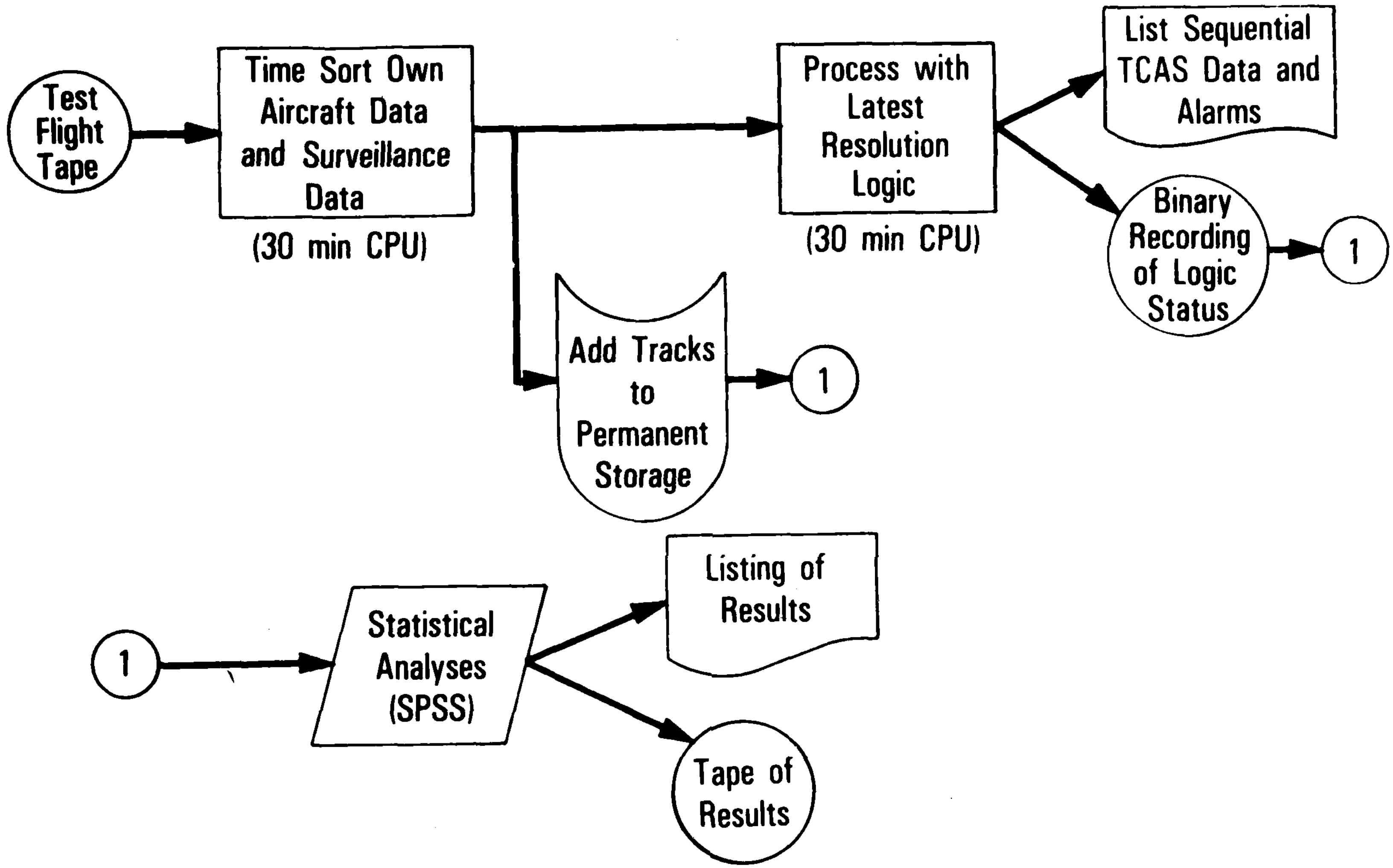
Uses Live Flight Test Surveillance Data

Compliments Flight Testing - Verifies Detection and Resolution Logic Performance as Implemented in TCAS Hardware

Permits Candidate Logic Evaluation Without Hardware Implementation

Data Base

- Over 40 Hours of Surveillance Data on All Traffic Seen by TCAS
- Various Traffic Densities: Chicago, Washington, Atlantic City
- Over 3000 Good Surveillance Tracks (10 or More Updates)
- Includes TCAS - TCAS Flights

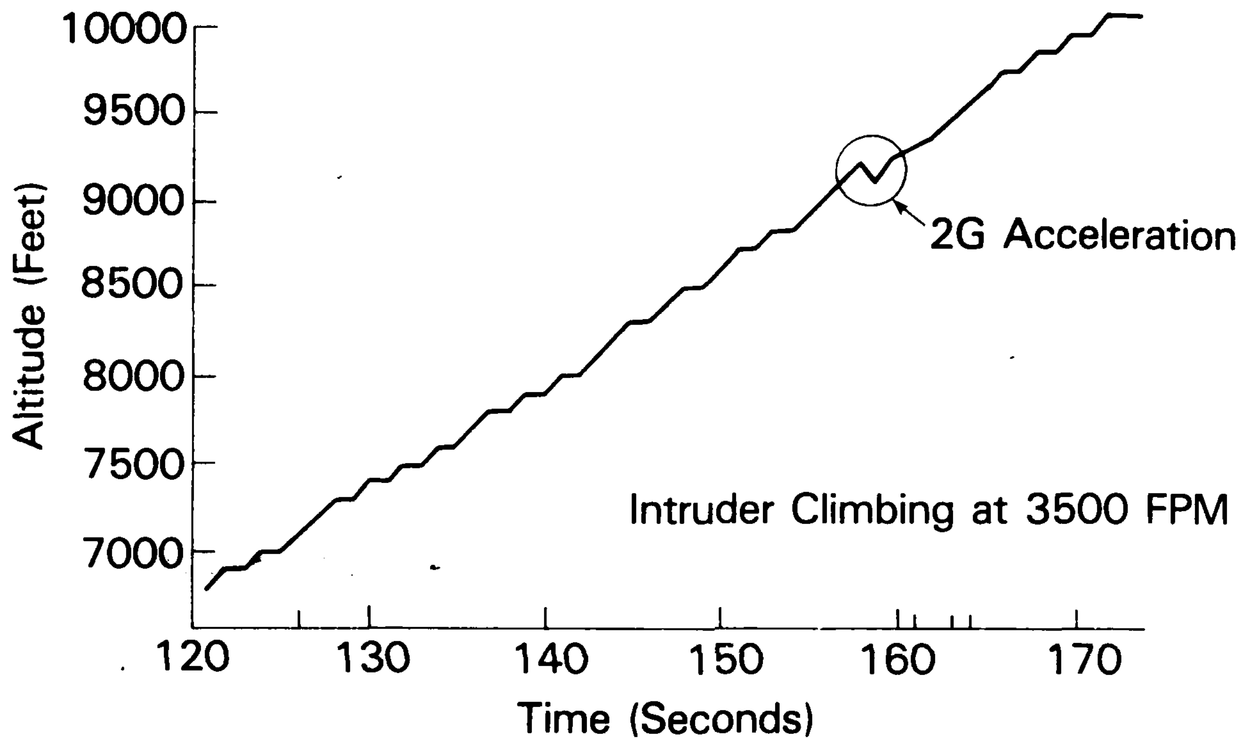


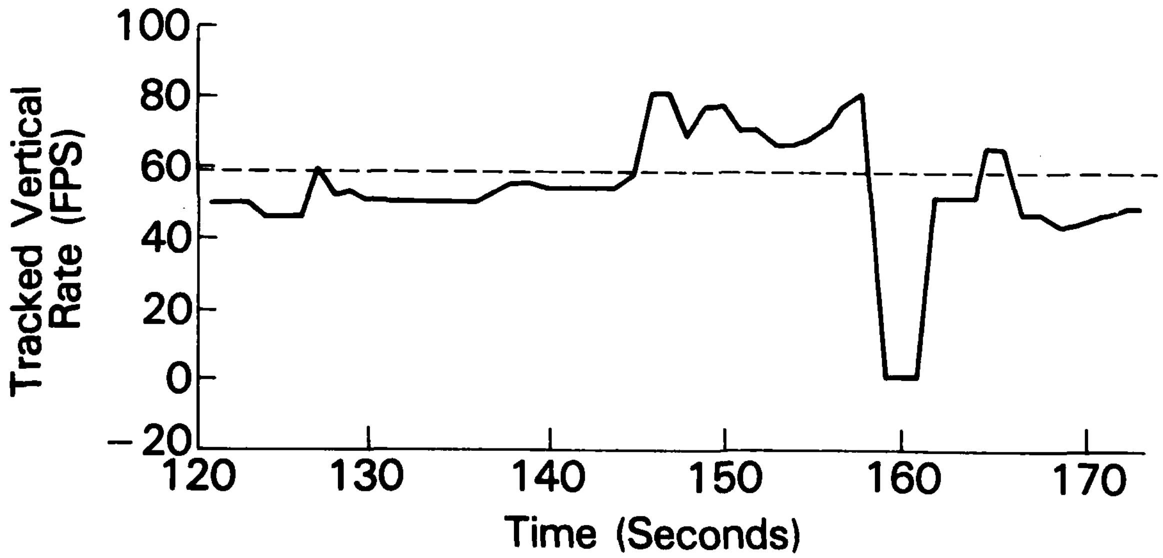
Surveillance Playback System

CASE STUDY 2

- IMPACT ON JUMPS IN MODE C SURVEILLANCE DATA
  - LARGE CORRELATION WINDOWS REQUIRED TO INSURE SURVEILLANCE TRACK SURVIVABILITY
  - 200 FEET CHANGES IN ONE SECOND IN SURVEILLANCE MODE C REPORT TO THREAT LOGIC CAN OCCUR
  - SURVEILLANCE MODE C PATTERNS CAN REPRESENT INCREDIBLE ACCELERATIONS
  - CAUSES LARGE FLUCTUATIONS IN TRACKED VERTICAL RATE
  - FILTER ADDED BETWEEN SURVEILLANCE TRACKING AND THREAT LOGIC TRACKING

Case Study 2: Piedmont Flight Tape #9

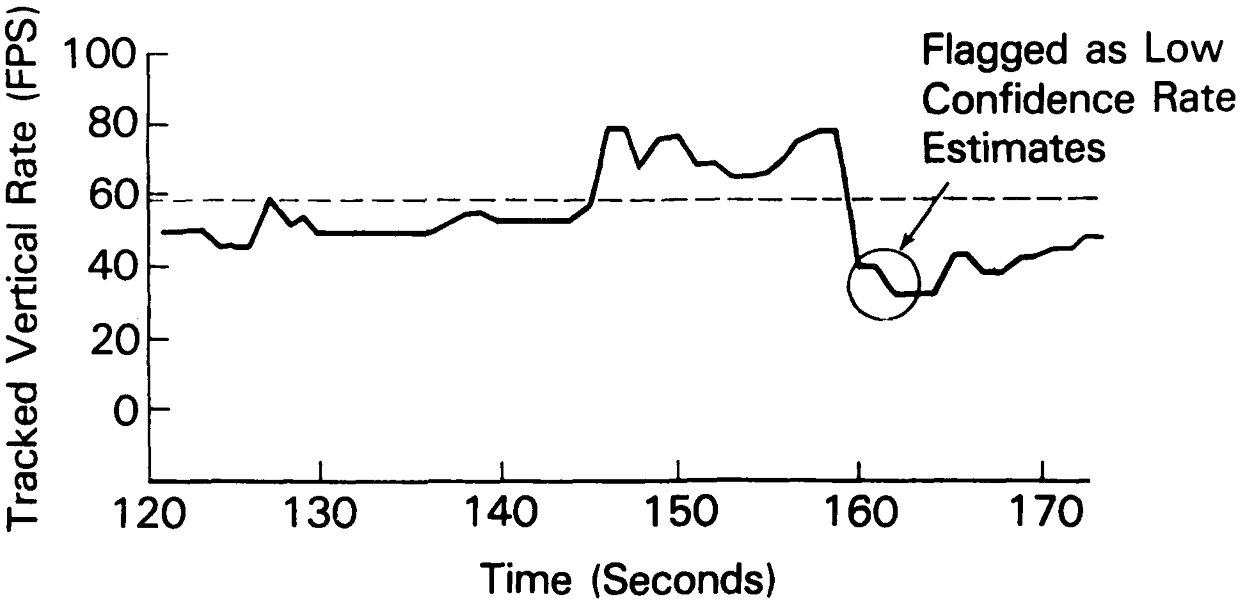




Case Study 2:

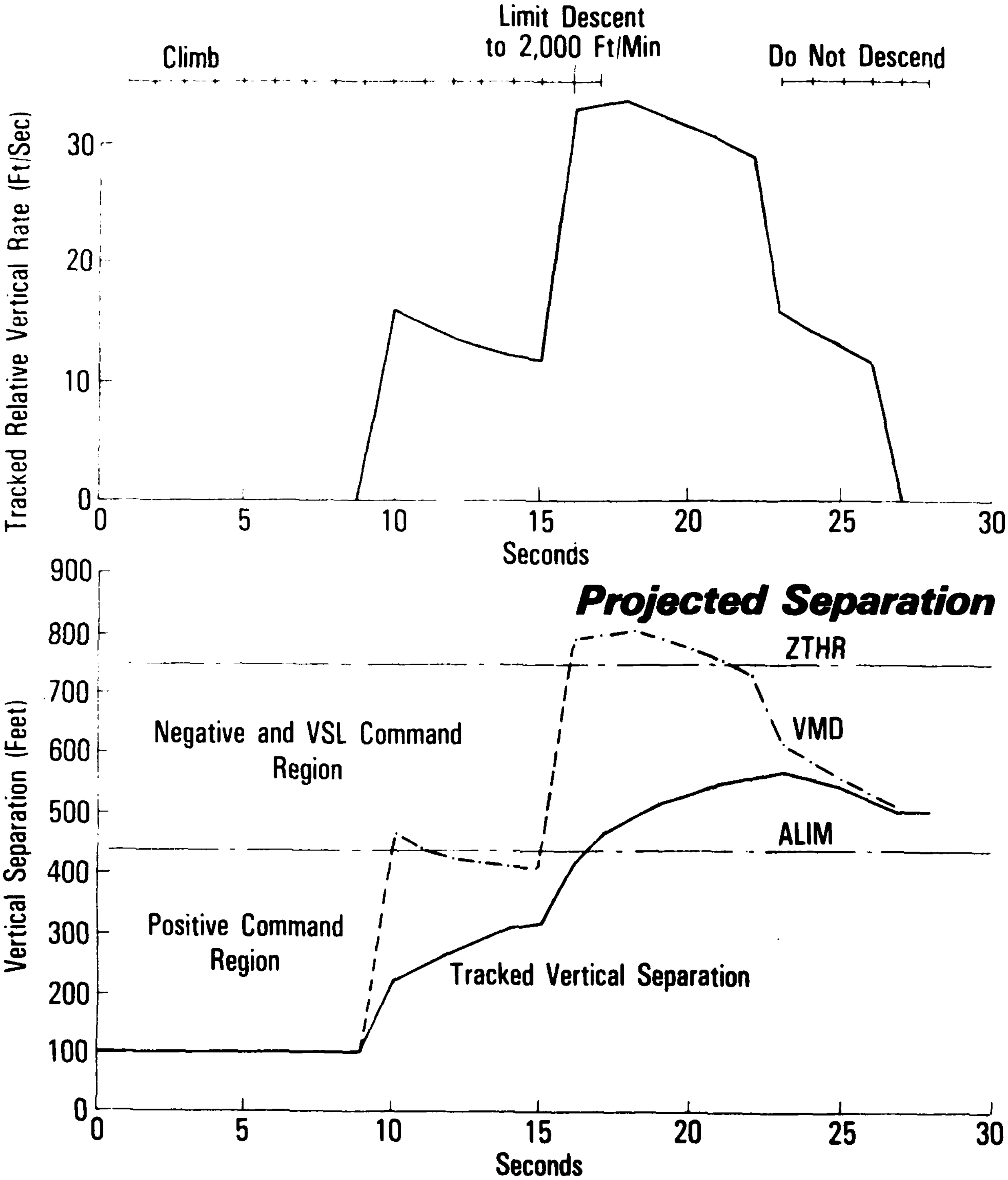
Lincoln Lab Filter Added to Test Credibility of Implied Acceleration in Surveillance Reported Mode-C Altitude.

Threat Logic Tracked Vertical Rate



CASE STUDY 3

- CLOSED LOOP PILOT FEEDBACK
  - PILOT RESPONSES CAUSED RESOLUTION OSCILLATION AND CONFUSING ADVISORY PATTERNS
  - PROBLEM ASSOCIATED WITH PROJECTED SEPARATION
  - POSITIVE ADVISORY IS NOW RETAINED UNTIL SEPARATION IS ACHIEVED



Impact of Pilot Response Causing Oscillating Command Patterns

SIGNIFICANT RESULTS

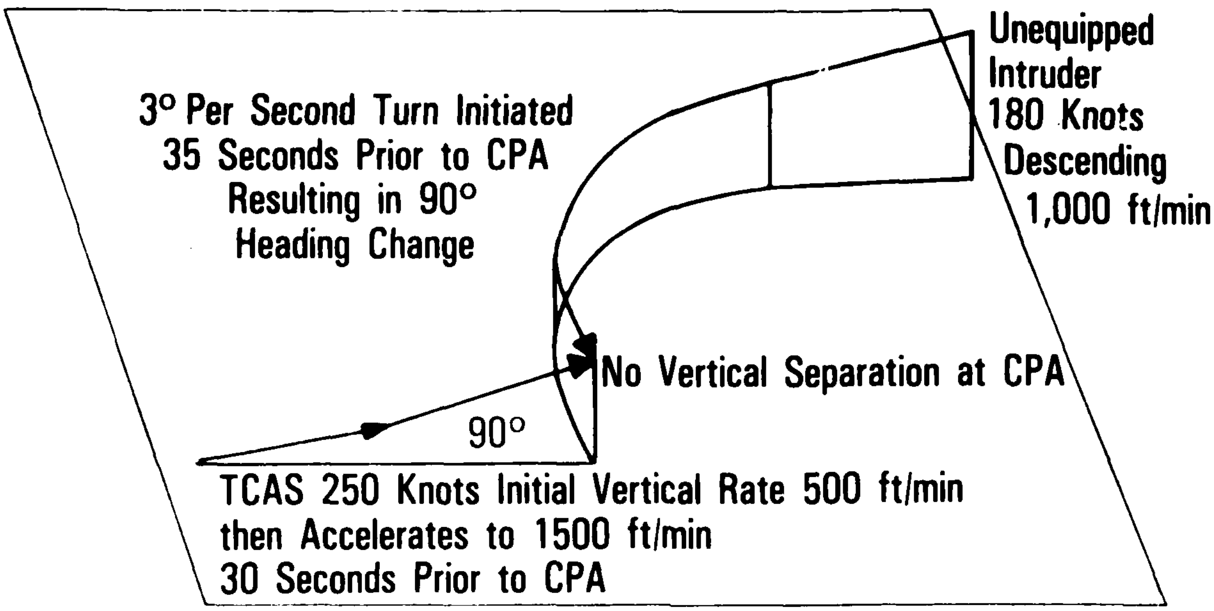
- LEVEL OF TESTING
  - OVER 17,000 ENCOUNTERS ANALYZED
  - ALL PREVIOUS TEST FLIGHT SURVEILLANCE DATA PLAYED AGAINST LATEST LOGIC REFINEMENTS
- EFFECTIVENESS
  - ALL LOGIC ISSUES DETECTED BEFORE FLIGHT TESTING
- REPORTS
  - TCAS LOGIC PERFORMANCE FOR ATCRBS THREATS
- PENDING
  - TCAS LOGIC PERFORMANCE FOR TCAS EQUIPPED THREATS AND ERROR DEGRADED PERFORMANCE ANALYSIS
  - TCAS LOGIC PERFORMANCE FOR MULTIPLE THREATS
- LOGIC STATUS
  - LOGIC CHANGES ARE REFINEMENTS/PARAMETRIC ADJUSTMENTS RATHER THAN MAJOR CONCEPTUAL CHANGES

NEW LOGIC RESULTS

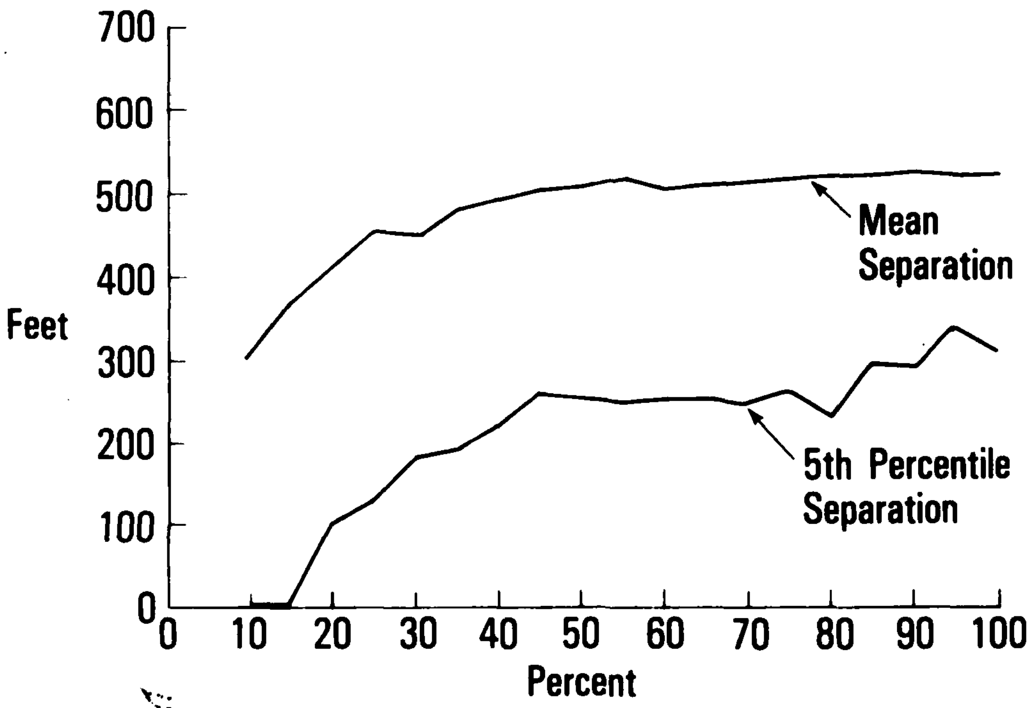
- DIGITAL AIR DATA COMPUTER INTERFACE IDENTIFIED
  - OPTIMAL ALPHA BETA PARAMETERS SELECTED FOR RATE ESTIMATION
- INTERIM RESULTS OF TAUDOT LOGIC ADDITION
  - 3 ALARMS DURING CHICAGO TEST FLIGHT ELIMINATED
- TRACK FIRMNESS LOGIC CAN DETECT 1/4 - 1/2 G ACCELERATIONS AND APPROPRIATELY DELAY SENSE SELECTIONS
- "ADVISORY NOT OK" LOGIC DOES DETECT INTENTIONAL "FAKE OUT" MANEUVERS

ONGOING EFFORTS

- LARGE DATA BASE OF WHAT THREAT LOGIC ACTUALLY SEES IS NOW AVAILABLE
  - 2 SEPARATE TCAS VIEWS OF SAME ENVIORNMENT
  - STANDARD DEVIATION IN SURVEILLANCE $\ddot{R}$ LESS THAN 12.6 FEET
- CONTINUE PARAMETER OPTIMIZATION USING REAL WORLD DATA BASE
  - TAUDOT SENSITIVITY
  - TRACK FIRMNESS DECLARATION
  - "ADVISORY NOT OK" SENSITIVITY
- ENHANCED TCAS II LOGIC DEVELOPMENT
- SUPPORT DEVELOPMENT OF PROBABILISTIC SYSTEMS SAFETY STUDY



Accelerating Threat Error Assessment Encounter



Surveillance Link Reliability

TCAS-II

OCTOBER 1982

DALMO VICTOR OPERATIONS
Bell Aerospace TEXTRON
Division of Textron Inc.

DV-10496

OVERVIEW

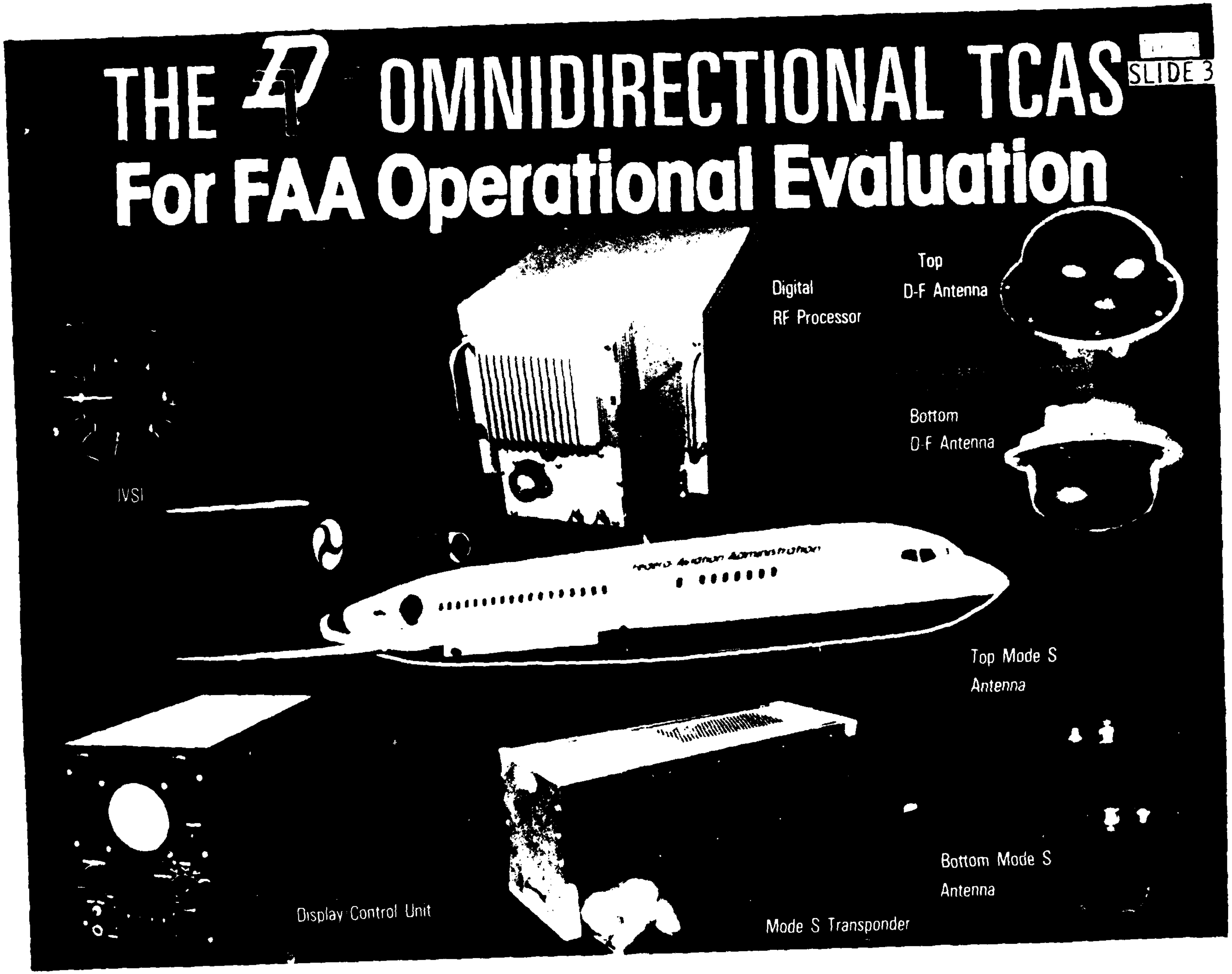
DALMO VICTOR HAS DELIVERED THREE PROTOTYPE SYSTEMS TO THE FAA OF THE OMNIDIRECTIONAL TCAS SYSTEM WHICH HAVE BEEN SUCCESSFULLY FLIGHT TESTED ON BOTH FAA AIRCRAFT AND ON PIEDMONT AIRCRAFT

OVERVIEW

- DALMO VICTOR OMNIDIRECTIONAL TCAS DESIGNED FOR AN ENVIRONMENT OF 12 AIRCRAFT IN 10 NMI
  - OMNI DIRECTIONAL INTERROGATION
  - 4 LEVELS OF WHISPER / SHOUT ATTENUATION TO SEPARATE TARGETS AT THE SAME RANGE
  - DISPLAYS TRAFFIC BEARING TO 8^0 RMS ACCURACY
  - SUCCESSFULLY FLIGHT TESTED ON FAA AIRCRAFT AND ON PIEDMONT AIRCRAFT

DALMO VICTOR OMNIDIRECTIONAL TCAS
FOR FAA OPERATIONAL EVALUATION

THIS VIEWGRAPH ILLUSTRATES THE HARDWARE FOR THE OMNIDIRECTIONAL TCAS SYSTEM. NOTE THAT BOTH TOP AND BOTTOM DIRECTION-FINDING ANTENNAS WERE PROVIDED AND THAT IN ADDITION TO THE IVSI DISPLAY, A DISPLAY UNIT IS PROVIDED FOR BEARING PROXIMITY WARNING. THE DIGITAL/RF PROCESSOR IS ENCOMPASSED WITHIN AN 8 MCU BOX


THE OMNIDIRECTIONAL TCAS
SLIDE 3
For FAA Operational Evaluation
Digital
RF Processor
Top
D-F Antenna
Bottom
D-F Antenna
IVSI
Top Mode S
Antenna
Bottom Mode S
Antenna
Display Control Unit
Mode S Transponder

OVERVIEW (CONT'D)

THE DALMO VICTOR TCAS II UPGRADES THE OMNIDIRECTIONAL DESIGN FOR OPERATION IN AN ENVIRONMENT OF 0.3 AIRCRAFT PER SQUARE NAUTICAL MILE. THIS DESIGN PROVIDES DIRECTIONAL INTERROGATIONS, AND 31 LEVELS OF WHISPER/SHOUT ATTENUATION TO ASSIST IN DEGARBLING RETURNS. THE DESIGN ALSO PROVIDES RANGE AND BEARING ADVISORIES TO TCAS I-EQUIPPED AIRCRAFT. THE DALMO VICTOR TCAS II UNITS ARE BEING USED BY THE FAA TO VERIFY MINIMUM OPERATIONAL PERFORMANCE STANDARDS

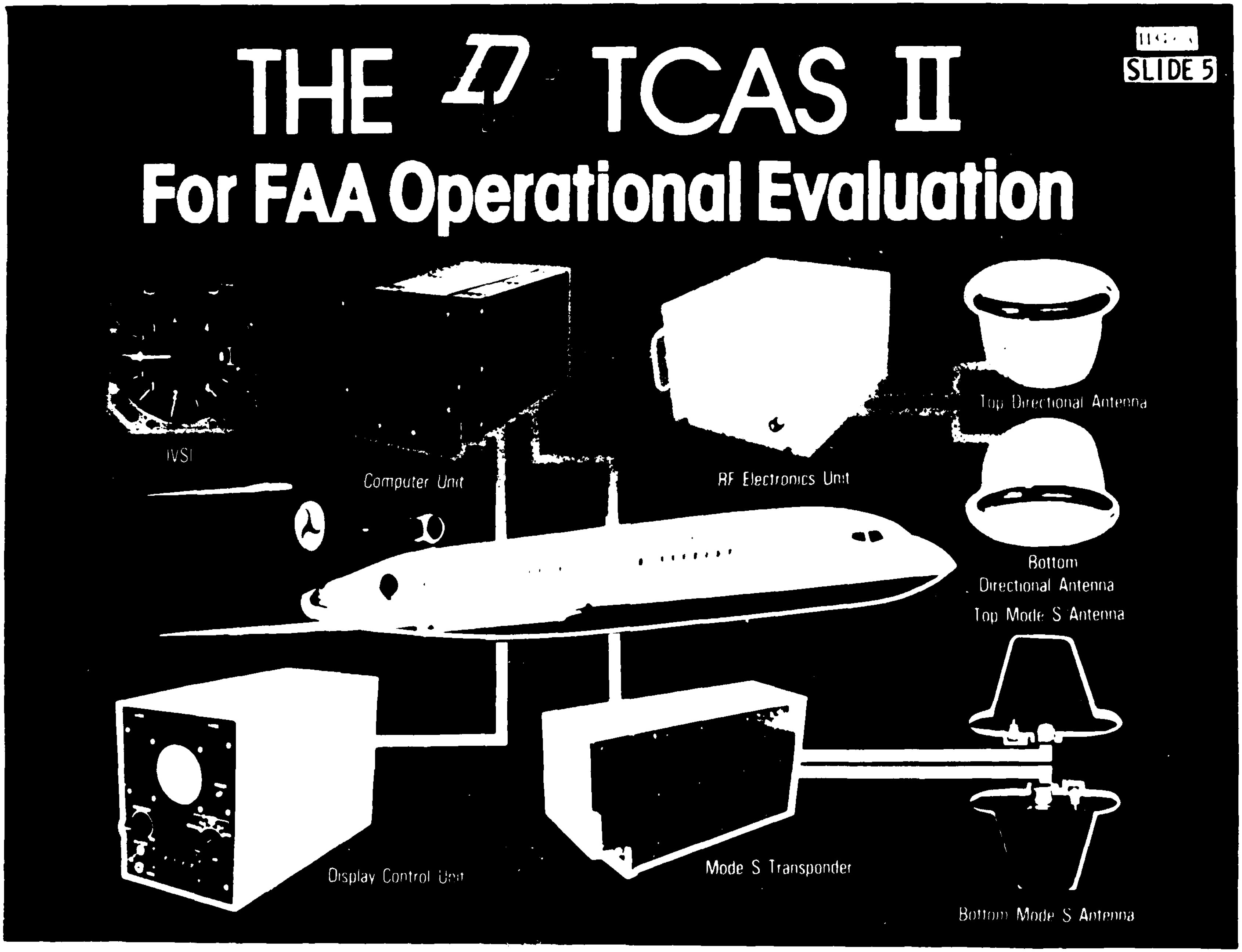
OVERVIEW (CONT'D)

- DALMO VICTOR TCAS-II UPGRADES THE OMNIDIRECTIONAL TCAS AND IS DESIGNED FOR A 0.3 AIRCRAFT PER SQUARE NAUTICAL MILE ENVIRONMENT

  - DIRECTIONAL INTERROGATIONS (90 DEGREE SECTOR)
  - 31 LEVELS OF WHISPER / SHOUT ATTENUATION ARE AVAILABLE TO SEPARATE TARGETS AT THE SAME RANGE
  - DISPLAYS TRAFFIC BEARING TO 8^{0} RMS ACCURACY
  - PROVIDES RANGE AND BEARING ADVISORY TO TCAS-I EQUIPPED AIRCRAFT
  - THE DALMO VICTOR TCAS-II UNIT WILL BE UTILIZED BY THE FAA TO VERIFY TCAS-II MINIMUM OPERATIONAL PERFORMANCE STANDARDS

THE DV TCAS II FOR FAA OPERATIONAL EVALUATION

THE DALMO VICTOR TCAS II INDUSTRY PROTOTYPE HARDWARE IS SHOWN IN THIS VIEWGRAPH. NOTE THAT BOTH TOP AND BOTTOM DIRECTIONAL ANTENNAS ARE PROVIDED. THESE ANTENNAS ARE LOW PROFILE AND CAN PROVIDE DIRECTIONAL INTERROGATIONS AS WELL AS BEARING INFORMATION. IN ORDER TO PROVIDE THE INCREASED PERFORMANCE FOR TCAS OPERATION THE COMPUTER UNIT IS PROVIDED IN A SEPARATE 6 MCU BOX WITH THE RF ELECTRONICS IN AN 8 MCU BOX.


SLIDE 5
THE TCAS II
For FAA Operational Evaluation
IVSI
Computer Unit
RF Electronics Unit
Top Directional Antenna
Bottom Directional Antenna
Top Mode S Antenna
Display Control Unit
Mode S Transponder
Bottom Mode S Antenna

TCAS II IMPROVEMENTS

THE IMPROVEMENTS SHOWN HERE WERE MADE TO THE OMNI-DIRECTIONAL DESIGN TO PROVIDE OPERATION IN HIGHER DENSITY

TCAS-II IMPROVEMENTS

- IMPROVED WHISPER / SHOUT
- DIRECTIONAL TRANSMISSION (90 DEGREE SECTOR)
- VARIABLE MINIMUM TRIGGER LEVEL (MTL) TO REDUCE THE EFFECT OF FRUIT PULSES
- SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY

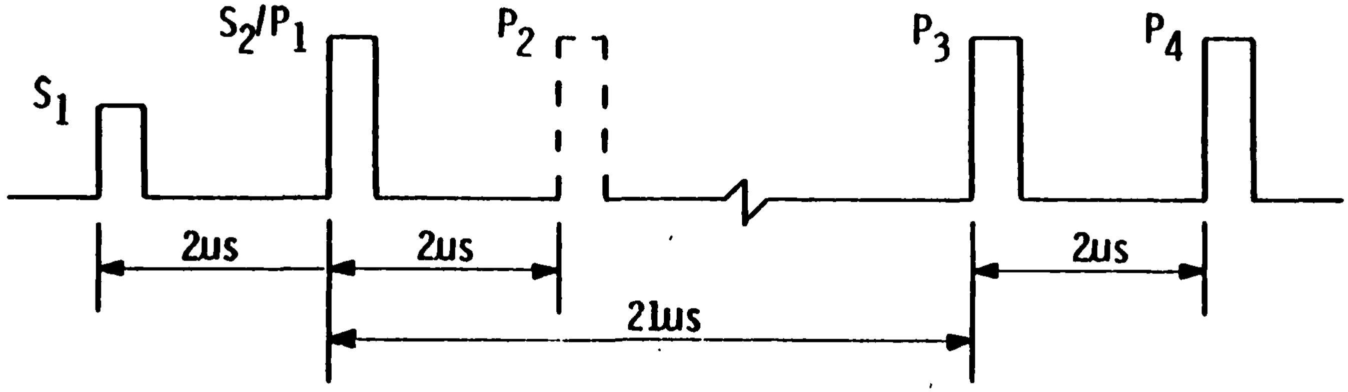
ATCRBS INTERROGATION PULSE SEQUENCE

THIS VIEWGRAPH SHOWS THE WAVEFORM DURING THE ATCRBS INTERROGATION. NOTE THAT IF A TRANSPONDER RECEIVES A STRONG P_2 PULSE ON THE NOTCH PATTERN THERE IS A POSSIBILITY THAT THIS PULSE IN COMBINATION WITH THE P_4 PULSE WILL SOLICIT INTERROGATIONS. THE SPACING IS EXACTLY 21 MICROSECONDS. FLIGHT TESTS WITH THE DALMO VICTOR TCAS II FEAS-IBILITY MODEL INDICATE THAT THERE ARE APPROXIMATELY 10 PERCENT EXTRA RETURNS DUE TO THIS PHENOMENA. THESE PULSES ARE EASILY COR-RELATED WITH THE NORMAL RETURNS FROM AN INTRUDER DUE TO THE FACT THAT THEY ARE RECEIVED EXACTLY TWO MICROSECONDS LATER

ATCRBS INTERROGATION PULSE SEQUENCE

11348-A

SLIDE 7



DESCRIPTION	ANTENNA PATTERN
S_1 SUPPRESSION PULSE ESTABLISHES WHISPER / SHOUT SUPPRESSION LEVEL	DIRECTIONAL
S_2 SUPPRESSION / P_1 INTERROGATION PULSE	DIRECTIONAL
P_2 SUPPRESSION PULSE	NOTCH
P_3 INTERROGATION PULSE	DIRECTIONAL
P_4 MODE S SUPPRESSION	DIRECTIONAL

TCAS II IMPROVEMENTS

(WHISPER/SHOUT OPERATION)

THE PREVIOUS OMNIDIRECTIONAL UNIT UTILIZED TWO SEPARATE SUPPRESSION PULSES PRIOR TO INTERROGATION WITH AN APPROXIMATE THREE TO FOUR MICROSECOND SPACING BETWEEN THE SECOND INTERROGATION SUPPRESSION PULSE AND THE FIRST INTERROGATION PULSE. NOW THAT WE ARE PROVIDING A P_2 SUPPRESSION PULSE ON THE NOTCH PATTERN, IT IS NECESSARY TO CHANGE THE TECHNIQUE OF PROVIDING SUPPRESSION PULSES SO THAT THE NOTCH PATTERN P_2 PULSE IS NOT SPACED EIGHT MICROSECONDS FROM THE FIRST SUPPRESSION PULSE WHICH MIGHT ILLICIT MODE A REPLIES. THUS, THE SINGLE PULSE SUPPRESSION TECHNIQUE SHOWN IN THE PREVIOUS VIEWGRAPH IS USED. THIS MEANS THAT THE WHISPER/SHOUT ATTENUATOR MUST HAVE A SWITCHING SPEED OF APPROXIMATELY ONE MICROSECOND.

ADDITIONAL WHISPER/SHOUT ATTENUATOR STEPS ARE NECESSARY TO PROVIDE DEGARBLING IMPROVEMENT IN THE DENSER ENVIRONMENT FOR OPERATION OF THE TCAS II SYSTEM. TWENTY-THREE 1 dB STEPS ARE REQUIRED PER THE PRESENT SEQUENCE DESCRIBED IN THE MINIMUM OPERATING PERFORMANCE STANDARDS

TCAS II IMPROVEMENTS

(WHISPER/SHOUT OPERATION)

- OMNIDIRECTIONAL TCAS UTILIZES TWO SEPARATE SUPPRESSION PULSES PRIOR TO INTERROGATION
- A SINGLE W/S SUPPRESSION PULSE IS USED WITH DIRECTIONAL TRANSMISSION SO THAT THE NOTCH PATTERN P_2 SUPPRESSION PULSE IS NOT SPACED 8 usec FROM FIRST W/S SUPPRESSION PULSE WHICH MIGHT ILLICIT MODE A REPLIES
- TCAS II WHISPER/SHOUT ATTENUATOR MUST HAVE A SWITCHING SPEED OF 1 MICROSECOND
- TWENTY-THREE ONE dB STEPS ARE REQUIRED PER SEQUENCE IN MOPS

TCAS II IMPROVEMENTS (CONT'D)

(DIRECTIONAL TRANSMISSION - 90^{0})

THE WHISPER/SHOUT INTERROGATION TECHNIQUE SUCCESSFULLY PROVIDES DEGARBLING OF RETURNS DUE TO THE FACT THAT ALL TRANSPONDERS THAT REPLY ARE OPERATING NEAR THEIR THRESHOLD OR MINIMUM TRIGGER LEVEL. THIS FACT MUST BE TAKEN INTO ACCOUNT WHEN DESIGNING THE ANTENNA NOTCH PATTERN FOR P_2 SUPPRESSION PULSES.

NOTCH PATTERN P_2 PULSES WILL SUPPRESS TRANSPONDERS WHICH WOULD NORMALLY REPLY TO INTERROGATIONS WHENEVER THE P_2 NOTCH PATTERN PULSE IS GREATER THAN THE P_2 INTERROGATION PULSE.

TRANSPONDERS ARE EXPECTED TO REPLY WHEN THE P_2 NOTCH PATTERN IS 3 dB LOWER THAN THE P_1 INTERROGATION PULSE, I.E., THE TRANSPONDER BECAUSE IT IS OPERATING NEAR ITS MTL DOES NOT SEE THE P_2 NOTCH PATTERN WHEN IT IS 3 dB LOWER THAN THE P_1 INTERROGATION PULSE

TCAS II IMPROVEMENTS (CONT'D)

(DIRECTIONAL TRANSMISSION (90°)

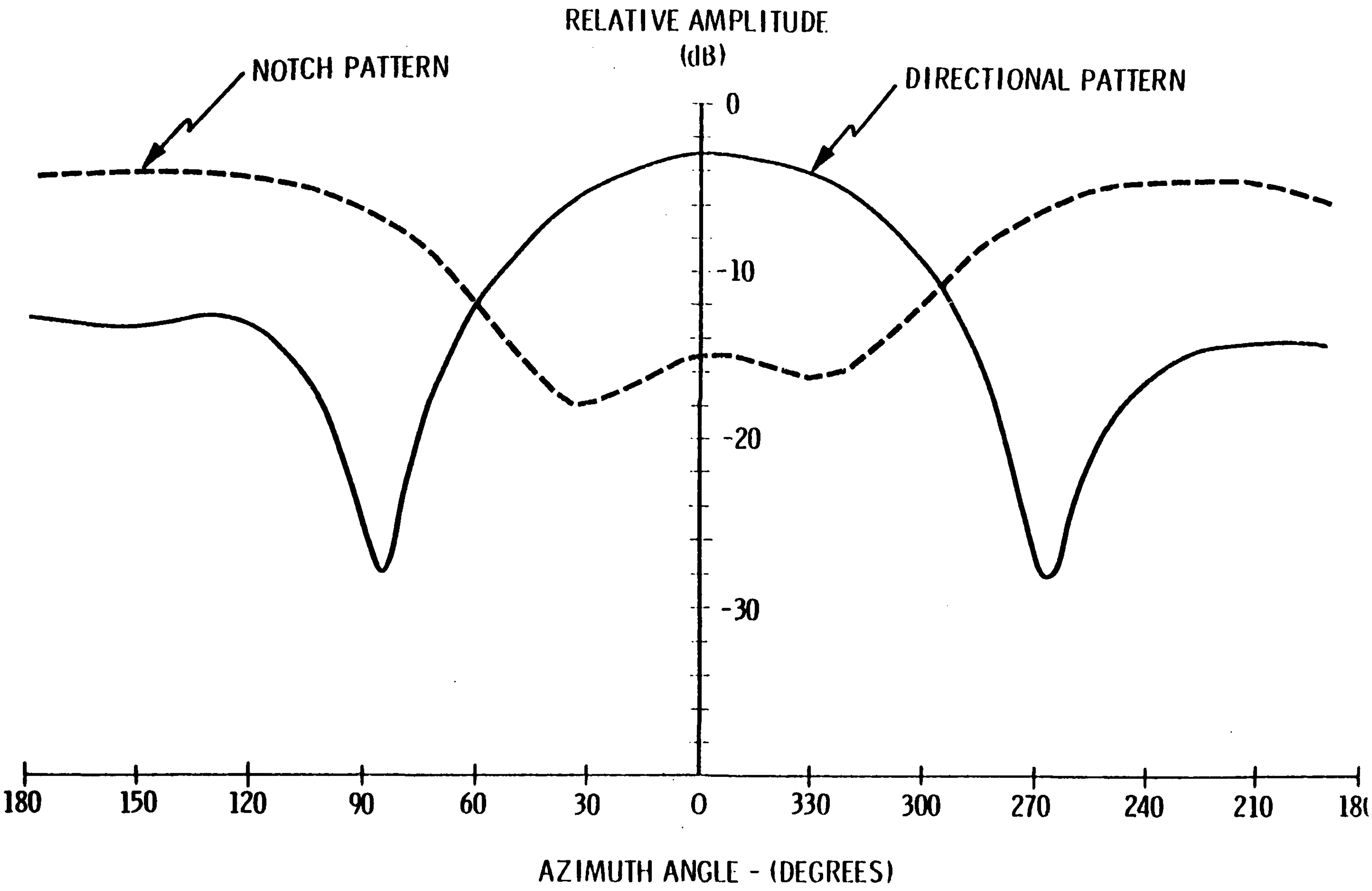
- TRANSPONDERS WHICH REPLY ARE OPERATING WITHIN A FEW dB OF MTL DUE TO WHISPER/SHOUT SUPPRESSION TECHNIQUE
- NOTCH PATTERN P_2 SUPPRESSION PULSES SUPPRESS TRANSPONDERS WHENEVER P_2 ON THE NOTCH PATTERN IS GREATER THAN THE P_1 INTERROGATION PULSE
- TRANSPONDERS ARE EXPECTED TO REPLY WHEN THE P_2 NOTCH PATTERN PULSE IS 3 dB LOWER THAN THE P_1 INTERROGATION PULSE

TYPICAL ATCRBS INTERROGATION ANTENNA PATTERNS

THIS IS A TYPICAL ANTENNA PATTERN OF THE TCAS II SYSTEM. THE DIRECTIONAL PATTERN IS USED FOR THE WHISPER/SHOUT SUPPRESSION PULSE, AND THE P_1, P_3, AND P_4 PULSES. THE NOTCH PATTERN IS USED FOR THE P_2 SUPPRESSION PULSE

11356-A
SLIDE 10

TYPICAL ATCRBS INTERROGATION ANTENNA PATTERNS



TCAS II IMPROVEMENTS (CONT'D)

(VARIABLE MINIMUM TRIGGER LEVEL (MTL))

IN ORDER TO REDUCE FRUIT, THE MTL OF THE SYSTEM IS VARIED IN ACCORDANCE WITH THE WHISPER/SHOUT ATTENUATION LEVEL, I.E., WHEN WE ARE TRANSMITTING HIGH POWER FOR LONG RANGES WE NEED GOOD RECEIVER SENSITIVITY. WHEN A TARGET IS CLOSE AND WE ARE TRANSMITTING LOW POWERS, WE CAN REDUCE THE RECEIVER SENSITIVITY WHICH ALSO REDUCES THE FRUIT THAT IS PICKED UP IN THE SYSTEM

TCAS II IMPROVEMENTS (CONT'D)

(VARIABLE MINIMUM TRIGGER LEVEL (MTL)

- MTL IS VARIED OVER A 17 dB RANGE IN ACCORDANCE WITH MOPS

  WHISPER/SHOUT TABLE TO REDUCE FRUIT PULSES

SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY

DUE TO THE DENSE ENVIRONMENT, IT HAS BEEN NECESSARY TO IMPROVE THE REPLY BUFFER MANAGEMENT. THIS HAS BEEN ACCOMPLISHED BY UTILIZING A NARROW RANGE WINDOW FOR CLOSELY SPACED INTERROGATIONS AND A WIDE RANGE WINDOW BETWEEN LARGER-SPACED INTERROGATIONS. ONE WOULD ALWAYS LIKE TO USE A NARROW RANGE WINDOW, HOWEVER, WHEN YOU TAKE INTO ACCOUNT AIRCRAFT MOTION, IT IS NOT POSSIBLE UNLESS THE INTERROGATIONS ARE CLOSELY SPACED.

THE IMPROVED BUFFER CORRELATES INTRUDERS WHICH ARE RECEIVED FROM MORE THAN ONE WHISPER-SHOUT LEVEL WITHIN THE SAME DIRECTIONAL SECTOR, THOSE THAT ARE RECEIVED FROM MORE THAN ONE DIRECTIONAL SECTOR, AND THOSE INTERROGATIONS WHICH GENERATE REPLIES DUE TO THE FACT THAT A TRANSPONDER SEES ONLY THE P_2 NOTCH PATTERN PULSE AND THE P_4 PULSE WHICH IS SPACED 21 MICROSECONDS APART

SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY

- IMPROVED REPLY BUFFER MANAGEMENT IS PROVIDED BY ALLOWING THE RANGE WINDOW USED TO ASSOCIATE TWO OR MORE REPLIES WITH THE SAME INTRUDER, TO BE A FUNCTION OF THE TIME BETWEEN CORRESPONDING INTERROGATIONS
  - NARROW RANGE WINDOW IS USED BETWEEN W/S INTERROGATIONS - WIDER RANGE WINDOW BETWEEN INTERROGATION SEQUENCES TO ALLOW FOR AIRCRAFT MOTION
- MULTIPLE REPLIES FROM THE SAME INTRUDER ARISE FROM THE FOLLOWING:
  - CLOSELY SPACED W/S LEVELS WITHIN THE SAME DIRECTIONAL SECTOR
  - OVERLAPS BETWEEN DIRECTIONAL SECTORS
  - INTERROGATIONS GENERATED BY NOTCH PATTERN P_2 PULSE AND P_4 PULSE

SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY (CONT'D)

THE TRACKING ALGORITHMS HAVE BEEN IMPROVED TO PROVIDE SMALL RANGE TRACK WINDOWS FOR ALL RANGES. THIS IMPROVES THE ABILITY TO CORRELATE RETURNS IN A DENSE ENVIRONMENT. THIS MINIMIZES EFFECT OF FRUIT AND FACILITATES TRACKING OF NON-MODE C AIRCRAFT. THE TRACKING ALGORITHMS HAVE ALSO BEEN MODIFIED TO WORK WITH VARIABLE INTERROGATION SPACING

SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY (CONT'D)

- PRECISION TRACKING ALGORITHMS ARE USED TO PERMIT THE USE OF SMALL RANGE WINDOWS AT ALL RANGES. THIS IMPROVES ABILITY TO CORRELATE RETURNS IN A DENSE ENVIRONMENT.
  - MINIMIZES EFFECT OF FRUIT
  - FACILITATES TRACKING OF NON-MODE C AIRCRAFT
- TRACKING ALGORITHMS HAVE BEEN MODIFIED TO WORK WITH VARIABLE INTERROGATION SPACING

SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY (CONT'D)

AS SHOWN HERE THE SOFTWARE HAS BEEN MODIFIED TO PROVIDE TRACKING FOR BOTH NON-MODE C AIRCRAFT AND INTRUDERS WITH ILLEGAL ALTITUDE CODES. THESE INTRUDERS ARE DISPLAYED ON A BEARING/PWI INDICATOR BASED UPON CAS LOGIC CRITERIA

SURVEILLANCE SOFTWARE MODIFICATIONS FOR HIGH DENSITY (CONT'D)

- BOTH NON-MODE C AIRCRAFT AND INTRUDERS WITH ILLEGAL ALTITUDE CODES ARE TRACKED

- NON-MODE C TARGETS ARE DISPLAYED ON BEARING PWI BASED UPON CAS LOGIC CRITERIA

TCAS II BEARING DETERMINATION

AN AMPLITUDE DIRECTION FINDING SYSTEM IS USED WHICH IS SIMILAR TO THAT USED BY MILITARY AIRCRAFT FOR RADAR WARNING DIRECTION FINDING SYSTEMS

TCAS II BEARING DETERMINATION

- FOUR BEAM AMPLITUDE MONOPULSE DIRECTION FINDING IS USED WHICH PROVIDES ACCURATE, HIGHLY RELIABLE, BEARING INFORMATION - SIMILAR TO DIRECTION FINDING SYSTEMS USED IN THOUSANDS OF MILITARY AIRCRAFT RADAR WARNING SYSTEMS

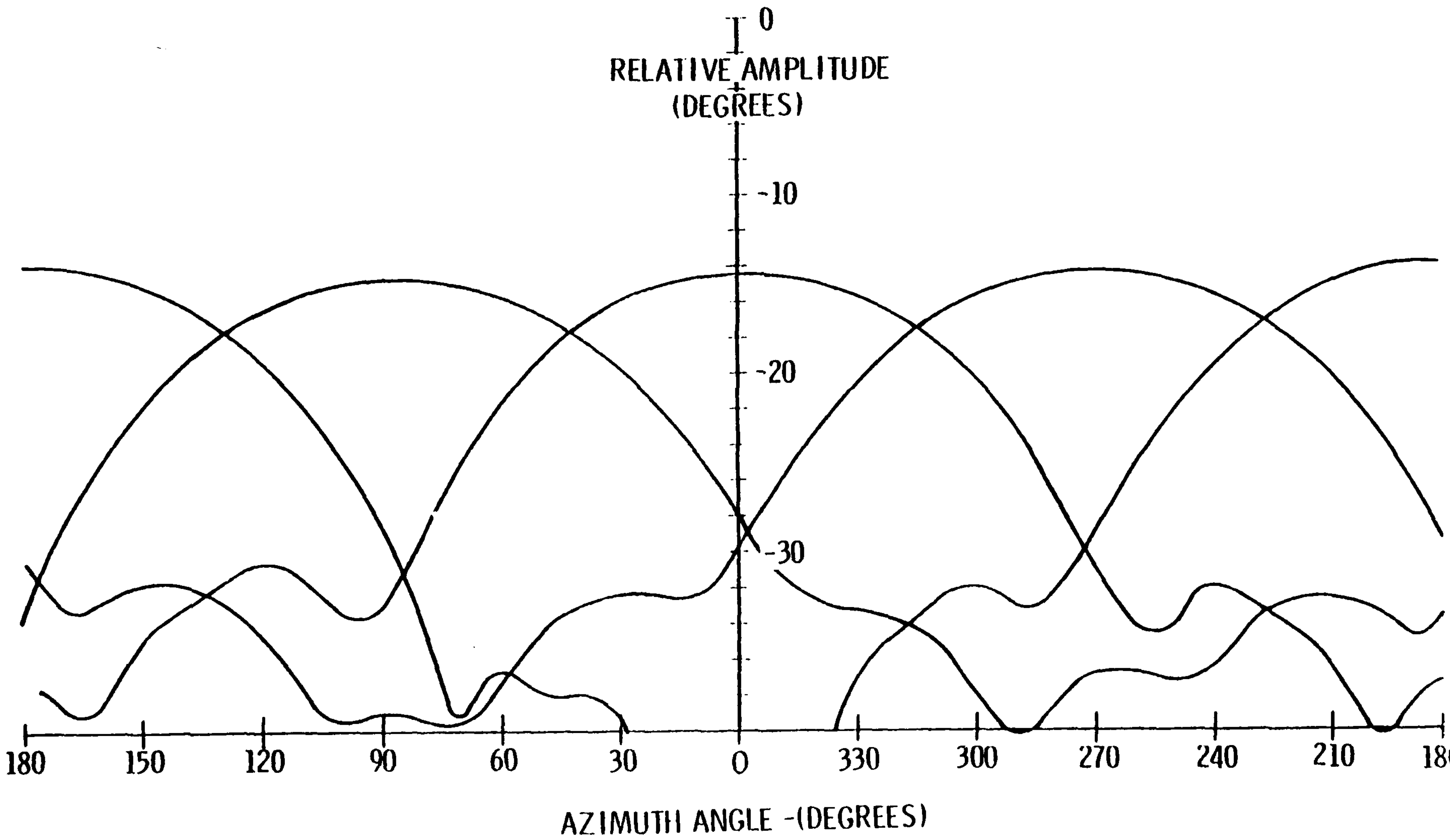
- DIRECTIVITY OF THE AMPLITUDE MONOPULSE BEAMS PROVIDE FRUIT DISCRIMINATION DURING BEARING MEASUREMENTS

DIRECTION FINDING RECEIVE BEAMS

THIS IS A TYPICAL PATTERN OF THE FOUR DIRECTION FINDING RECEPTION BEAMS TAKEN ON A LARGE GROUND PLANE IN AN ANECHOIC CHAMBER

DIRECTION FINDING RECEIVE BEAMS

11354-A
SLIDE 16



SYSTEM BEARING ACCURACY

SYSTEM BEARING ACCURACY IS PRESENTED FOR THE ANTENNA INSTALLED ON A LARGE GROUND PLANE IN THE ANECHOIC CHAMBER

SYSTEM BEARING ACCURACY

(MEASURED ON GROUND PLANE IN ANECHOIC CHAMBER)

AZIMUTH ANGLE (DEGREES)	BEARING ERROR (DEGREES)
0	-3
20	+9
40	+3
60	-9
80	-3
100	+3
120	+2
140	-7
160	-5

AZIMUTH ANGLE (DEGREES)	BEARING ERROR (DEGREES)
180	-5
200	+1
220	+3
240	-13
260	-11
280	-10
300	-6
320	-15
340	+1

RMS ERROR = 7.6^0

CONCLUSION

THE COLLISION AVOIDANCE SYSTEMS DEVELOPED BY DALMO VICTOR HAVE DEMONSTRATED THE CAPABILITY OF PROVIDING TIMELY AND USEFUL TRAFFIC ADVISORIES OF POTENTIAL COLLISION SITUATIONS.

THE IMPROVEMENTS MADE IN THE TCAS II SYSTEM ARE EXPECTED TO PROVIDE EXCELLENT COLLISION PROTECTION IN AN ENVIRONMENT OF 0.3 AIRCRAFT PER SQUARE NAUTICAL MILE.

CONCLUSION

- DIRECTIONAL INTERROGATION AND IMPROVED WHISPER SHOUT SEQUENCE HAVE BEEN TESTED AND GIVE SATISFACTORY RESULTS

- THE TCAS II SYSTEM WILL BE FIRST EVALUATED ON A FAA AIRCRAFT AND THEN ON AN OPERATIONAL CARRIER AIRCRAFT (PIEDMONT)

THE DALMO VICTOR TCAS II PIEDMONT CONFIGURATION

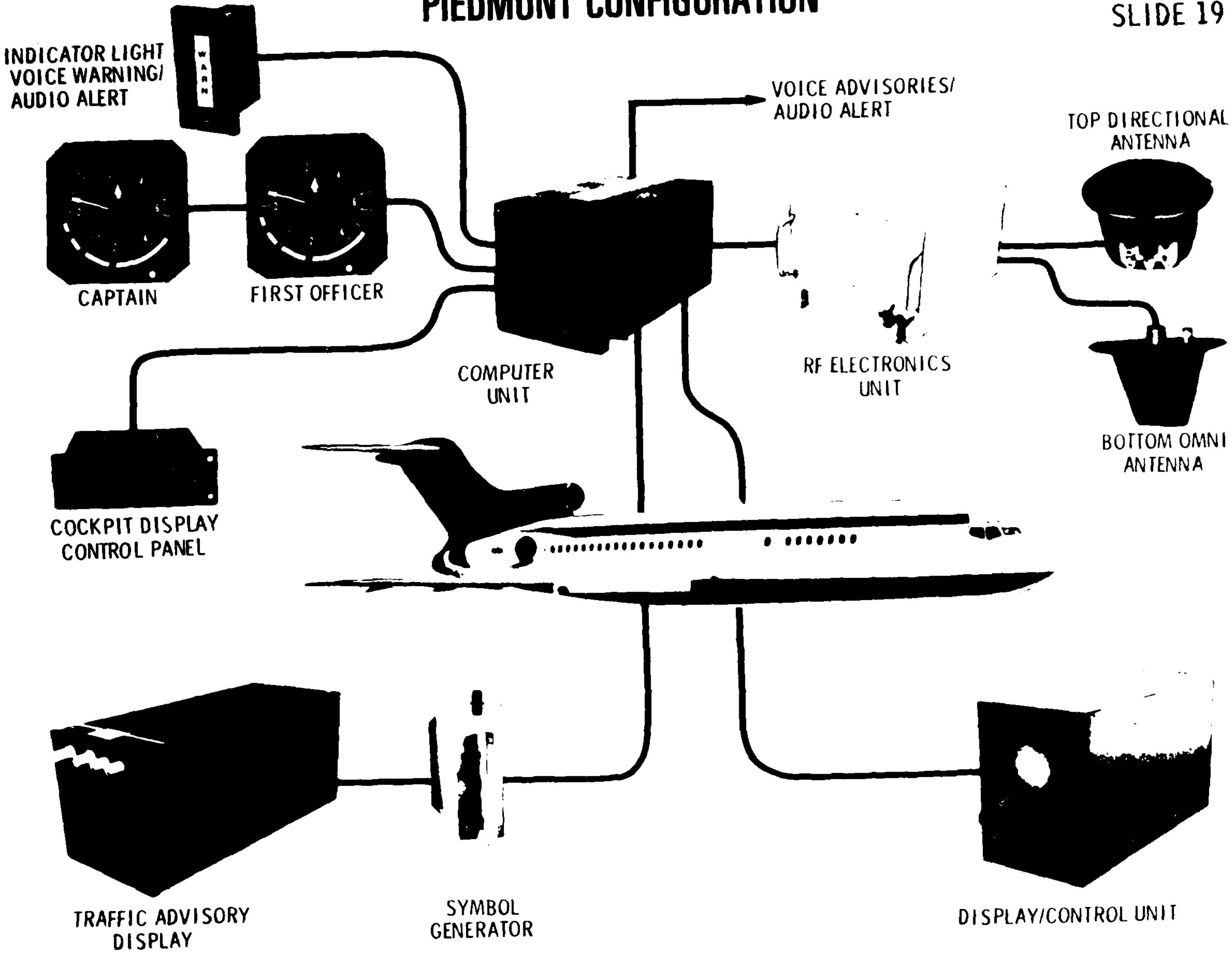
THIS VIEWGRAPH DEPICTS THE HARDWARE UNITS THAT WILL BE PROVIDED IN THE NEXT PIEDMONT EVALUATION. NOTE THAT THE BOTTOM ANTENNA IS NOW OMNI-DIRECTIONAL, IN ACCORDANCE WITH THE LATEST TCAS II MOPS. THE TOP ANTENNA PROVIDES DIRECTIONAL INTERROGATIONS AND BEARING INFORMATION. THIS UNIT HAS AN INDICATOR LIGHT, VOICE WARNING, AND AUDIO ALERT. TRAFFIC ADVISORY DISPLAY WILL BE VISIBLE BY THE PILOT. DUAL IVSIs ARE PROVIDED: ONE FOR THE CAPTAIN AND ONE FOR THE FIRST OFFICER

THE TCAS II

PIEDMONT CONFIGURATION

11338-B

SLIDE 19



EVALUATION OF TCAS II

IN AN AIR CARRIER ENVIRONMENT

W. L. HYLAND

OCTOBER 12, 1982

PROGRAM ENGINEERING AND MAINTENANCE SERVICE
FEDERAL AVIATION ADMINISTRATION
WASHINGTON, D.C. 20591

SLIDE 1

At our last conference we discussed in detail the objectives of our TCAS Operational Evaluation Program. We identified the areas that must be examined before we can implement the system with the degree of confidence we feel is necessary for an airborne collision avoidance device. We have undertaken a series of efforts intended to bring the Federal Aviation Administration (FAA) and the aviation community to this degree of understanding.

A two-part cockpit simulation with the Boeing Aircraft Company is underway which will evaluate the display media and use of the TCAS information under workload, principally in IMC conditions. The first part of that effort was completed in March of this year. We are conducting a parallel, limited effort at Lincoln Laboratory with available displays to advance the knowledge of participants in operational problems, principally in VMC conditions, while conducting the Boeing simulations. An initial (Phase I) effort with Piedmont Airlines, intended to build a large data base with TCAS II in actual line operations, was completed in March. We intend then to combine our knowledge from the simulations, the Lincoln Laboratory flights and the initial Piedmont flights into a series of tests in the FAA Technical Center B-727. We propose to follow this with a Phase II test in Piedmont aircraft for a further confirmation of TCAS operational performance.

SLIDE 2

At Boeing, methods for alerting the crew to TCAS information were evaluated consistant with alerting methodology developed jointly by the Boeing, Lockheed and Douglas aircraft companies under a master caution and warning study. The key factor was the time to gain the pilot's attention, given other on-going duties. Several methods of presenting resolution advisory (RA) information were considered, including the modified Instantaneous Vertical Speed (IVSI) Instrument, Light Emitting Diode (LED) panel. and voice. For traffic advisories (TAs) a simple light, and several configurations on a Cathode Ray Tube (CRT) were considered.

SLIDE 3

A report on the results of the Boeing Developmental Limitation will be available this November. In general. the results indicated that for best performance the next tests should use an IVSI to display RAs, coupled with an audio tone alerter, and supported by a voice confirmation. The TA information should be identified by an audio tone, and information provided on a plan-view type of CRT.

SLIDE 4

We have completed the first part of our tests at Lincoln Laboratory in a C-421 aircraft to gain experience with the use of traffic advisory information in visual meteorological (VMC) conditions. This test configuration used the modified IVSI, and Bendix weather radar display for traffic information. A traffic advisory precursor was provided either by a 5 sec. precursor voice alert, or a 15 sec. Tau precursor on the CRT with an audio tone. Traffic within 3 nmi and ± 1500 feet was shown at all times A limited number of pilots have flown, but those had some experience with TCAS.

SLIDE 5

The CRT display provided information in this form: own altitude (10,500'), traffic 500 feet above at approximately two o'clock (+ 05), and at seven o'clock, 400 feet below (04). A two mile range ring was used continuously. The other information was for test purposes.

Another configuration used on the CRT display listed in tabular form the range, relative altitude and bearing.

SLIDE 6

Pilots consistantly find the tabular display difficult to use, because of continuing need to read and interpret the information. With each update, a new interpretation is required.

A precursor alert appeared to be successful in gaining the pilot's attention, but rather than preparing him for the RA, it was used to initiate a visual search for the intruder.

When the pilots were given an RA with instructions to follow the command, they were distracted from most duties until he located the threatening aircraft.

Providing the bearing of the threat produced a significant improvement in visual acquisition.

While pilots suggested that additional information would be useful, it was found that any more than the simplest, quick reference information was not useful.

In vertical encounters pilots have a reluctance to cross-altitudes, and requested knowledge of the threats vertical direction. (Note: this is consistant with the same pilot reaction observed in-flights in the B-727 at the FAA Technical Center).

SLIDE 7

The first phase of the Piedmont Airlines tests was completed in March of this year. The test program was conducted for the FAA by ARINC Research Inc. The project manager was Mr. Thomas Berry, who will join the panel for questions and answers at the end of the session. During this project, the management and staff of Piedmont Airlines were exceptionally helpful in their cooperation with this evaluation.

The display equipment was installed at the observers position. The observers were asked to report on the conditions accompanying each one of the alerts. The two B-727s flew a total of 928 hours with the equipment on board, 131 hours of which had one or more observers. To deal with the desensitization question (i.e., adaption of threat volume and alerting to the environment) concerning alerts for aircraft on the ground, all RAs were inhibited below 500 feet above the ground (by radio altimeter).

SLIDE 8

A standard modified IVSI provided RA information. This display was small, with a three-inch CRT. The display was threat-based, i.e., it was not activated until a threat with a 15 second longer Tau than the RA activated the display. Only traffic satisfying the closing threat criteria was displayed. A two-mile range ring was used, and when traffic was inside the two-mile ring, the ring doubled in size.

SLIDE 9

Despite the RA inhibiting at 500 feet, the TCAS still generated a number of advisories for traffic on the ground. Filtering the ground-based traffic, RAs were generated once in 37 hours of flying, and TAs once in 5.1 hours. Half of the TAs were below 2000 feet, including seven that occurred in one holding pattern going into Chicago. Most of the encounters occurred in the forward direction. The Vertical Speed Minimums (VSMs) did not appear to be a factor. Most of the RAs were Vertical Speed Limites or negatives. Almost half of the RAs would not have required deviation from current flight path, these being classed as preventive RAs. For all of the observed RAs the crew was able to make visual confirmation.

SLIDE 10

We plan to provide a better way of eliminating ground advisories.

When more than one aircraft was in the area in which a TCAS alert was given, the identification of the threat was difficult.

Traffic advisories were useful in cases where no ATC advisory was given, but where the pilot was interested in the information. The advisories provided acceptable augmentation to ATC advisories. Pilots expressed a desire to be able to see traffic on the TCAS display when ATC traffic was called.

The RAs were found to be appropriate, but some questions were raised as to whether a less severe maneuver would be satisfactory, e.g., where a "don't climb" would be appropriate instead of "descend".

SLIDE 11

Example Encounters

SLIDE 12

From the results of these tests, we are concluding the following:

The alert rate experience seems to be at an acceptable level. The Tau values selected for RAs and TAs, and the changes in those levels at 10,000 feet and 2,500 feet seem adequate. The aircraft on the ground will be eliminated in the next tests by comparing the aircraft's altitude with own aircraft's radio altimeter.

There appears to be a need to examine the utility of displaying proximate traffic other than the threat, includng non-Mode C traffic to avoid misidentification problems when a threat has been presented. Also, it appears that there is a need to examine the utility of the pilot being able to "call-up" the display to identify traffic on an intermittant basis in support of his visual acquisition responsibility. Additionally, Piedmont Airlines has raised the possibility of the use of TCAS in non-radar areas.

SLIDE 13

For the next tests we will use the following:

- An IVSI for RA information
- A CRT that is shared with the Weather Radar, operating for TCAS only when required.
- The TCAS will activate the display similarly to the Dalmo Victor display in Phase I, that is with 1) a Mode C aircraft meeting the necessary closing range and altitude Tau criteria, 2) with a non-Mode C aircraft meeting the necessary closing range criteria, or 3) by a pilot request with a 15 second timeout.

SLIDE 14

Example display

SLIDE 15

This display shows a compendium of the display alphanumerics available for the test. The upper left tabular listing provides a means for range and altitude information on an intruder when bearing is lost. It may have limited use in this particular test, but is included as a system capability. The upper right symbol will allow an off-screen target to be displayed at the edge of the display, if required.

SLIDE 16

This describes the proposed procedural philosophy to be used during the initial phase of the operational evaluation in Piedmont Airlines B-727. These procedures are specifically for this evaluation and may or may not be the procedures employed in later phases, or when TCAS is operationally implemented. In this phase TCAS RAs will not be followed in IMC conditions. If a maneuver is executed that requires violation of an ATC clearance, it will be understood that a pilot is invoking his normal emergency authority in response to the encounter situation and communication with ATC will be required.

SLIDE 17

Our next effort in the Boeing B-737 simulator is planned to begin in December.

The Lincoln Laboratory Phase II is underway now and will be conducted through early December.

The whole package will be integrated in the FAA Technical Center B-727, the performance confirmed in this aircraft and made available for the aviation community to observe, and the final configuration for Piedmont Phase II shaken down. This effort will begin in April.

Finally, we expect to move into the Piedmont Airlines aircraft about June.

We invite your interest and participation in the evaluation program outlined, and look forward to your participation in preparing for the next phase of the program as announced by the previous speakers.

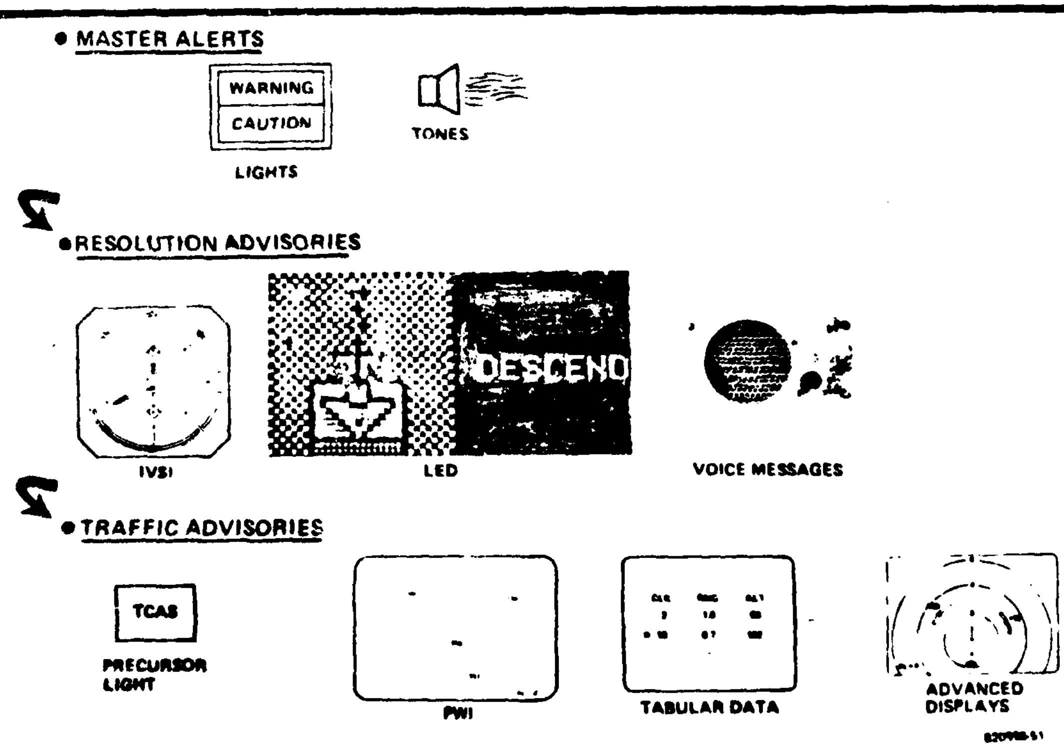
#1

Technical Approach

	Boeing		Linc. Lab	Piedmont		FAA Tech Ctr.
	Dev. Sim.	Oper. Sim.	C-421	Ph 1	Ph 2	B-727
Display Elements	X	X				
Traf. Info		X	X			X
Cockpit Workload		X	X			X
Oper. Procedures		X	X		X	X
Desens. Scheme				X		X
Oper. Perf. Demo.				X	X	X
Pilot Train. Req.					X	

#2

TCAS Display Options



BOEING DEVELOPMENTAL SIMULATION RESULTS

INITIAL ALERTING

- DETECTION (DETECT ALERT CONDITION):
  - FASTEST WITH LIGHT AND SOUND
  - SLOWEST WITH MORE COMPLEXITY IN DISPLAY
- RESPONSE (BEGIN RESPONSE TO ALERT CONDITION):
  - MOSTLY DEPENDENT ON DETECTION TIME
  - MOST PILOTS USED TA TO ANTICIPATE
  - VISUAL & VOICE IS FASTEST. EASIEST TO FOLLOW

PILOT OPINIONS ON METHODS OF DISPLAY:

- TABULAR DISPLAY WAS RATED POORLY
- GRAPHIC DISPLAY FOR TA'S MORE USEFUL THAN ATC TFC ADV.
- VERTICAL MOVEMENT REQUESTED

RECOMMENDATIONS FOR RETROFIT AIRCRAFT:

- ADHERE TO QUIET, DARK COCKPIT WHERE POSSIBLE (E.G., MASTER CAUTION/WARNING)
- RA: IVSI, VOICE, SIREN
- TA: CRT, C-CHORD

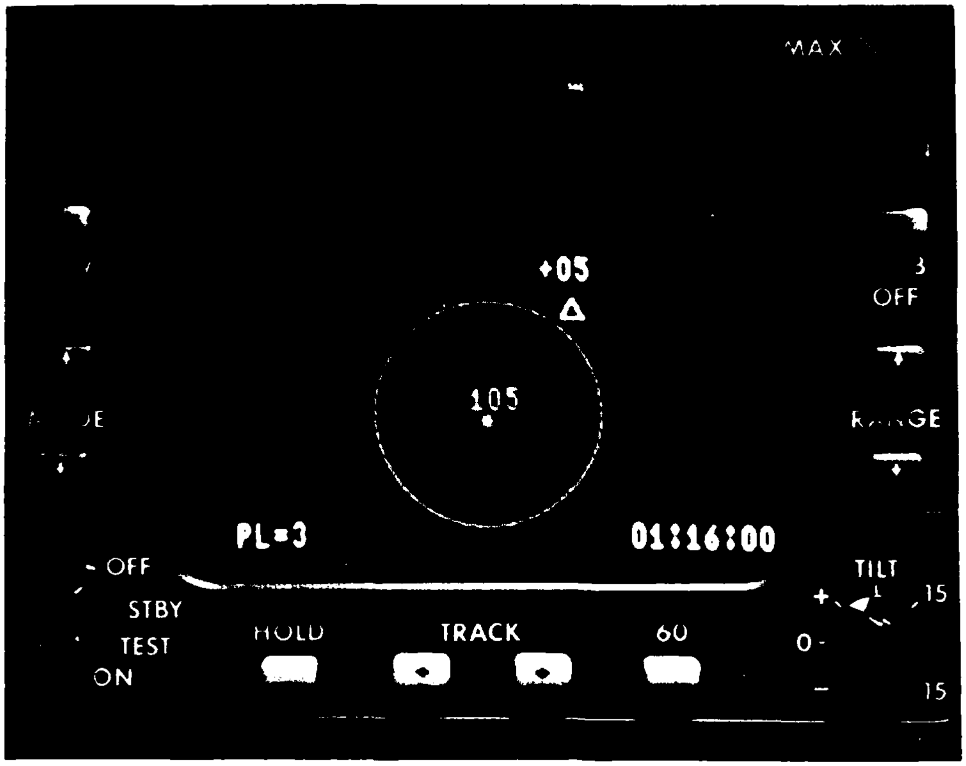
LINCOLN LAB C-421, PHASE I

- EQUIPMENT:
  - C-421
  - LL TCAS EXP UNIT (TEU) WITH AOA ANTENNA
  - IVSI, CRT (WX RADAR DISPLAY)
- FLIGHTS:
  - 60 PLANNED, 10 UNPLANNED ENCOUNTERS, TERMINAL APPROACHES
  - 3 EXPERIENCED PILOTS (FAA, NASA)
- INFORMATION:

IVSI	CRT
CLIMB/DESCEND	TABULAR: RANGE, RELATIVE ALTITUDE, BEARING
DON'T CLIMB/DESCEND	PPI: RANGE BEARING (CLOCK PSN.) RELATIVE ALTITUDE OWN ALTITUDE (ABSOL.) RANGE RING
LIMIT/MAINTAIN RATE	

AUDIO	CONFIGURATION
AUDIO TONE	IVSI W/5 SEC. VOICE PRECURSOR
VOICE = "ALERT"	TABULAR AND PPI WITH 15 SEC. TAU PRECURSOR; APPROX @ 3NMI, ± 1500 FEET

#5



Display Configuration for
Phase I Lincoln Laboratory Tests

#6

LINCOLN LAB C-421, PHASE I
RESULTS (JULY 1982)

- TABULAR DISPLAY UNDESIRABLE (HIGH WORKLOAD TO INTERPRET)
- 5 SEC. PRECURSOR USED FOR VISUAL SEARCH RATHER THAN ALERT PILOT
- PILOT DISTRACTION W/RA UNTIL VISUAL ACQUISITION
- BEARING INDICATION PRODUCED MARKED IMPROVEMENT IN VISUAL ACQUISITION
- ALL BUT SIMPLEST SET OF INFORMATION RESULTS IN PILOT RELUCTANCE TO USE ADVISORY INFORMATION
- ADD VERTICAL RATE (DIRECTION) INDICATOR

#7

PIEDMONT OPERATIONAL EVALUATION

PHASE I

- **EQUIPMENT:**
  - 2 PIEDMONT B727's
  - DALMO VICTOR TCAS W/AOA ANTENNA
  - IVSI AND CRT AT OBSERVERS POSITION

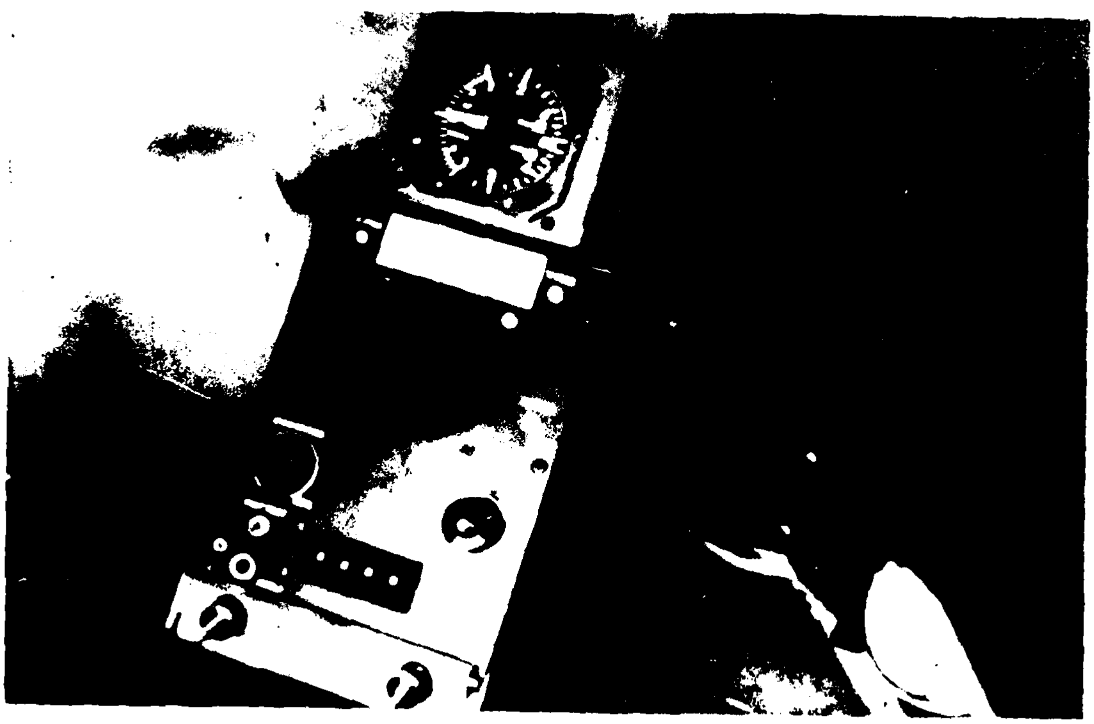
- **FLIGHTS:**
  - 928 HOURS (131 HOURS WITH OBSERVERS)
  - 24 TERMINAL AREAS
  - 21 PILOT/OBSERVERS (REPUBLIC, AMERICAN, FAA, NASA, PIEDMONT, DELTA, ALPA, US AIR)

- **INFORMATION:**

IVSI	CRT
CLIMB/DESCEND	ONE COLOR
DON'T CLIMB/DESCEND	THREAT ONLY AIRCRAFT, 15 SEC TAU PRECURSOR
LIMIT RATE	TRAIL
MAINTAIN RATE	RELATIVE ALTITUDE
	2 MILE RING, AUTOSCALE, FLASHING WHEN RA, AND
	BEEPING TONE ALERT TONE WHEN TA

- **OPERATIONAL CONFIGURATION:** INHIBIT RA's BELOW 500 FEET

#8



IVSI, Dalmo Victor Control & Display Unit
Piedmont Airlines Evaluation

#9

PIEDMONT OPERATIONAL EVALUATION

PHASE I RESULTS

- RESOLUTION ADVISORIES (RA): 1/29 HOURS (1/37 HOURS FOR AIRBORNE A/C)
- TRAFFIC ADVISORIES (TA): 1/2.8 HOURS (1/5.1 HOURS FOR AIRBORNE A/C)
- RANGE OF ADVISORIES
  - 50% TA's BELOW 2000 FEET, 20% ABOVE 10,000 FEET
  - TRAFFIC FROM ALL BEARINGS, 80% FROM FORWARD 180 DEGREES
  - OF OBSERVED TA's: 50% = AIR CARRIER
    6% = G/A
    32% = NOT IDENTIFIED BY TYPE
  - NO VSM's (1st ADV.)
  - 75% OF RAs = VSLs OR NEGATIVES, 24% = POSITIVE
  - OF OBSERVED RA's: ALL HAD VISUAL CONFIRMATION, PROPER DIRECTIONS

#10

PIEDMONT OPERATIONAL EVALUATION

ANALYSIS OF PHASE I OBSERVER DATA

- OBSERVERS STRESSED NEED TO ELIMINATE GROUND ADVISORIES
- PILOTS OFTEN EXPRESSED DESIRE TO SEE TRAFFIC CALLED BY ATC WHICH DID NOT APPEAR AS TA (SPECIFIC COMMENTS WERE MADE WHEN MULTIPLE SIGHTINGS OCCURRED AND IDENTIFICATION OF TCAS TRAFFIC WAS DIFFICULT)
- TRAFFIC ADVISORIES WERE GENERALLY REGARDED AS USEFUL WHEN NO PRIOR ATC ADVISORY HAD BEEN ISSUED
- TRAFFIC ADVISORIES WERE GENERALLY FOUND TO BE ACCEPTABLE IN AUGMENTING ATC ADVISORIES
- RESOLUTION ADVISORIES WERE GENERALLY FOUND TO BE APPROPRIATE, ALTHOUGH SEVERITY WAS OCCASIONALLY QUESTIONED

#11

EXAMPLE ENCOUNTERS

TCAS OPERATIONAL EVALUATION - PIEDMONT AIRLINES

1. Approach to Norfolk (Descending)
   - ATC = Advised traffic DC-7 at 3500' advised to level at 4000
     - TCAS = Traffic 1 o'clock, 500' below, 5 miles
       - TCAS = (at 2.5 mi.) "Don't Descend"
         - Passed 3/4 mile, 500' below, behind
2. Departure from Norfolk (Climbing Out)
   - ATC = Advised traffic 11 o'clock, 3 miles, in left turn, 4500'
     - ATC = Advised to level at 4000'
       - Visual contact
         - TCAS = Traffic 11 o'clock, 2 miles, 200' above
           - ATC = Requested visual verification
             - Passed coaltitude to left
3. Departure from Norfolk (Level 8000')
   - ATC = Traffic 12 o'clock, 3 miles, southbound, 8500'
     - TCAS = Traffic 1 o'clock, 3 miles, 500' above, closing
       - ATC = Advised "clear to climb when clear of traffic"
         - TCAS = (while climbing with traffic in site) "Don't Climb"
           - Crossed altitude, passed at .7 mile
4. Approach to Tampa (Descending)
   - ATC = Cleared to 4000'
     - (No ATC traffic advisory)
       - TCAS = Traffic 4 miles, then 3 miles, 12 o'clock, 300' below
         - TCAS = "Don't Descend"
           - Visual acquisition 12 o'clock
             - Passed slightly to left and below
5. En Route to Charlotte (Level at FL-260)
   - (No ATC advisory)
     - TCAS = Traffic 10 o'clock, beyond 4 miles, 1100' above, descending
       - Visual acquisition
         - TCAS = "Descend", "Don't Climb", "Descend", "Don't Climb"
           - TCAS = Traffic 900' above
             - Passed above ahead .6 mile

#12

PIEDMONT OPERATIONAL EVALUATION

PHASE I CONCLUSIONS

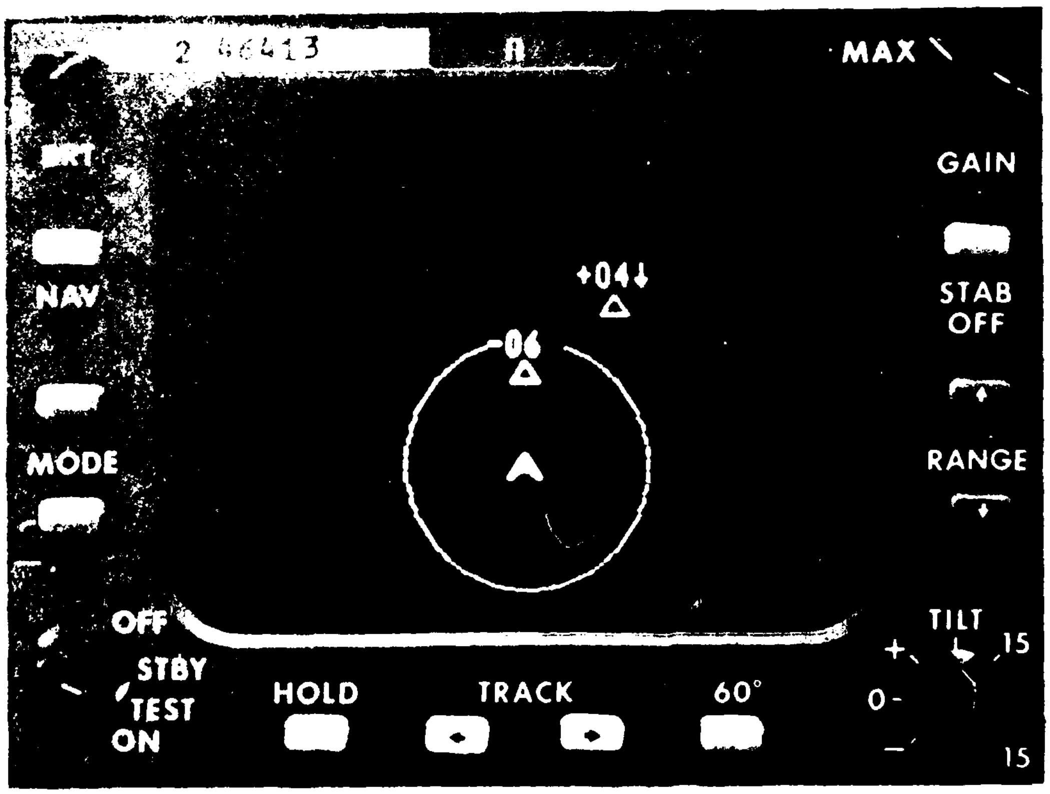
- ALERT RATE NOT EXCESSIVE. CONTINUE WITH PRESENT RA AND TA TAU VALUES
- DESENSITIZE (INHIBIT) ALL TRAFFIC ON GROUND BY USING RADIO ALTIMETER
- NEED TO EXAMINE INCLUSION OF OTHER NEARBY TRAFFIC (WITHIN SPECIFIED DISTANCE) ON DISPLAY WHEN ACTIVATED BY THREAT
- NEED TO EXAMINE ADDITION OF CAPABILITY FOR PILOT TO ACTIVATE TRAFFIC DISPLAY ON DEMAND

#13

<u>SELECTED DISPLAY INFORMATION</u>
<u>FOR NEXT TCAS TESTS</u>

- IVSI
  - STANDARD INFORMATION
- CRT (SHARED WX RADAR)
  - THREAT BASED ACTIVATION (15 SEC. TAU. PRECURSOR TO RA). ACTIVATED BY:
    - MODE C TRAFFIC MEETING RANGE AND ALTITUDE TAU CRITERIA
    - NON-MODE C TRAFFIC MEETING RANGE TAU CRITERIA (BELOW 14,000 FEET)
    - PILOT SWITCH (15 SECOND TIMEOUT)
  - INFORMATION PROVIDED
    - THREAT TRAFFIC ACTIVATING DISPLAY (MODE C/NON-MODE C) = AMBER
    - OTHER NON-THREAT TRAFFIC WITHIN 2 NMI, $\pm$ 1200 FEET = WHITE
    - RA TRAFFIC (WITH IVSI ADVISORY) = RED
    - VERTICAL DIRECTION
- AUDIO
  - RA: TONE INITIALLY, REPEAT FOR EACH CORRECTIVE ADVISORY, REINFORCE WITH VOICE
  - TA: TONE INITIALLY, TONE AGAIN IF NEW TA

#14-A

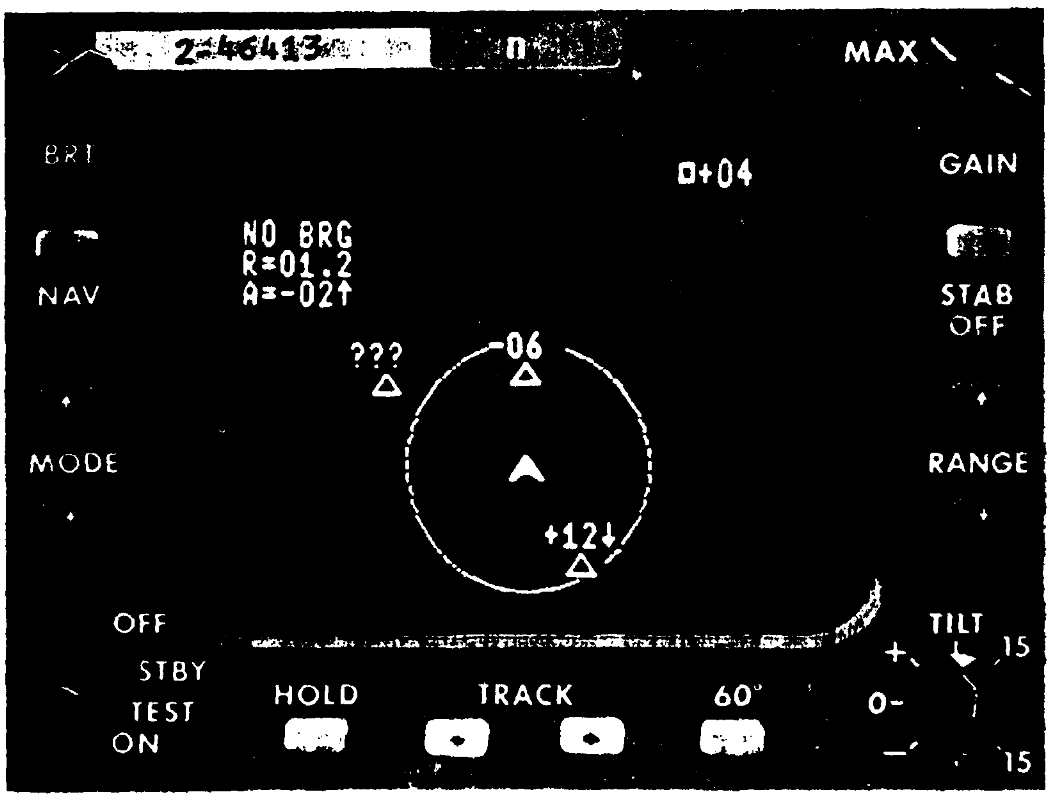


Example Display #1
Lincoln Laboratory Phase II

#14-B

Example Display #
[illegible] Laboratory Phase II

#15



Example Display #[illegible] (Compendium of Capabilities)
[illegible] Laboratory Phase II

#16

PROPOSED PILOT PROCEDURAL PHILOSOPHY
FOR PIEDMONT PHASE II

TYPE	PROCEDURE
TRAFFIC ADVISORY	• UNDERTAKE VISUAL SEARCH • COMM. W/ATC IF TRAFFIC STATUS IN QUESTION • W/VISUAL ACQUISITION, NORMAL SEE-AND-AVOID APPLIES
RESOLUTION ADVISORY	
NEG/LIMIT RATE	• MUST HAVE VISUAL ACQUISITION • IF DEVIATION FROM FLIGHT PATH INDICATED, MUST BE ABLE TO CLEAR AIRSPACE IN DIRECTION OF MOVEMENT • CONTROL VERTICAL RATE TO KEEP IVSI NEEDLE OUT OF YELLOW ARC • IF DEVIATION FROM ATC CLEARANCE, ADVISE ATC
CLIMB/DESCEND	• MUST HAVE VISUAL ACQUISITION • MUST BE ABLE TO CLEAR AIRSPACE IN DIRECTION OF INDICATED MOVEMENT • MANEUVER AIRCRAFT TO ACHIEVE 1500 FPM RATE, OR CONTINUE PRESENT RATE IF GREATER THAN 1500 FPM • ADVISE ATC

#17

NEXT OPERATIONAL EVALUATION EFFORTS

	BEGIN
• BOEING OPERATIONAL SIMULATION - IMC PROCEDURES - B737 TRAINING SIMULATOR	12/82
• LINCOLN C-421, PHASE II - VMC PROCEDURES - ENCOUNTERS AND TERMINAL AREAS	3/82
• FAA TECHNICAL CENTER B-727 - COMPLETE CONFIGURATION - ENCOUNTERS & NAS TOUR - TRAINING TECHNIQUES - SHAKEDOWN FOR AIR CARRIER, PHASE II	4/83
• AIR CARRIER PHASE II (PIEDMONT) - FULL CONFIGURATION - PILOT USE	6/83

Utility of Traffic Advisory Information

John W. Andrews

13 October 1982

Lincoln Laboratory

Massachusetts Institute of Technology

Lexington, Massachusetts 02173

Slide 1

OVERVIEW

This presentation summarizes the findings of FAA-sponsored evaluations of the operational utility of TCAS II traffic advisories. It begins by tracking the history of previous test programs involving subject pilots and automated traffic advisories. It then explains the operational context of the TCAS II automated traffic advisory. Results of the testing done to date are presented. Finally, some areas in which further testing and development will be undertaken are outlined.

Slide 2

PRINCIPAL SUBJECT PILOT TESTS OF AUTOMATED TRAFFIC ADVISORIES

Our current understanding of the utility of automated traffic advisories owes much to the seven subject pilot test programs listed here. These programs have investigated the type of TA information required, methods of information display, and the ability of pilots to use TA information. Ground cockpit simulators have proven useful in their ability to simulate a wide variety of encounter situations under highly controlled conditions. Flight tests have proven valuable in understanding the very important effect of the visual scene upon pilot response.

In addition to these tests, other efforts not involving human subjects have examined system alarm rates and resolution effectiveness. And studies of historical mid-air collisions have helped define the types of missing information that might have prevented these accidents.

It should be cautioned that despite the impressive amount of test and simulation data, no answers are final until TCAS II proves itself in actual operational use. All other test efforts are directed toward ensuring success in the ultimate test of actual operation.

Slide 3

TCAS II FLIGHT TEST OPERATIONS AT M.I.T. LINCOLN LABORATORY

Many of the examples that will be used later in the presentation will be drawn from the flight test experiences with TCAS II at Lincoln Laboratory. In these tests, a subject pilot flying a TCAS-equipped Cessna 421 experienced planned intercepts with a Beech Bonanza. In addition to planned encounters, TCAS experience was accumulated in unplanned encounters with non-test aircraft (targets-of-opportunity) who happened by chance to pass close to the TCAS aircraft.

Slide 4

TA INFORMATION CONTENT

As currently envisioned, TCAS II will provide horizontal position, altitude, climbing/descending status, and TCAS urgency status for each intruder that passes criteria for display.

Slide 5

PPI DISPLAY FORMAT

Several display formats have been examined in testing. The most promising uses a PPI format on a color CRT.

Pilot utilization of TCAS II TA's is aided by the use of three urgency levels associated with the colors red, amber, and white. The most urgent level is threat (red). This level corresponds to aircraft that have satisfied the criteria for issuance of resolution advisories. The second most urgent level is pre-threat (amber). This level signifies that a resolution advisory will be generated within 15 seconds if closing rates do not change. The lowest urgency level is proximity (white). This level corresponds to traffic that is in close proximity, but is not urgent at the current tracked closing rates.

Proximity advisories differ from the other TA types in an important respect: pilots are under no obligation to monitor or use a proximity advisory unless they judge it to be of interest. Aural alerts must be sounded when a pre-threat advisory appears. No aural alerts are required when a proximity advisory appears.

Slide 6

USES OF TCAS II TA'S

There are three principal uses of TCAS II TA's. The first is to stimulate the successful application of conventional separation assurance techniques before the use of TCAS resolution advisories becomes necessary. This helps guarantee the compatibility of TCAS with ATC. It also helps guarantee that TCAS is employed only when the primary techniques (ATC separation and "see-and-avoid") are incapable of resolving the situation.

The second major function is to allow correlation of TCAS resolution advisories with visually sighted or ATC-called traffic. The visual scene and ATC-generated information often provide the pilot with compelling and relevant information not available from TCAS. If this information is improperly integrated into the pilot's picture of the encounter situation, then confusion and inappropriate responses may result. TCAS TA's alert the pilot to multi-aircraft situations and assist in proper identification of intruders.

The third major function is to allow confirmation that successful resolution has been achieved. This function provides an important extra margin of safety if TCAS is to be used against uncooperative intruders or intruders for which accurate altimetry cannot be guaranteed.

The following three slides provide examples which illustrate each of the three principal uses.

Slide 7

STIMULATION OF CONVENTIONAL RESOLUTION

This slide depicts a subject pilot encounter which occurred on 19 August 1982. The intercept was planned to produce a turning encounter while the TCAS aircraft was in a holding pattern. On the basis of his visual sighting and the verification from TCAS that traffic was nearly co-altitude, the pilot elected to delay his turn. He immediately called ATC and obtained approval to extend the holding pattern for another mile. The use of TCAS resolution advisories was avoided.

Slide 8

VISUAL/TA CORRELATION

In this encounter the visually sighted aircraft, which was the initial object of crew concern was in reality not the most critical intruder. The pilots used the resolution advisory to avoid the fast, long-range threat while visually verifying adequate separation from the nearby slowly-closing aircraft.

Slide 9

CONFIRMATION OF RESOLUTION ADVISORIES

Because TCAS II traffic advisories indicate the position of the intruder causing the resolution advisory, it is possible for the pilot to visually confirm that the resolution advisory is achieving safe separation. If the resolution advisory is ineffective (e.g. due to bad altimetry), then the pilot may select other means of maintaining separation.

The encounter depicted in the slide occurred between the Lincoln Laboratory Cessna 421 and a target of opportunity during practice missions on 9 July 1982. The Lincoln Laboratory test pilot chose to ignore the resolution advisory and maintain visual separation from the intruder. Subsequent analysis indicated that the cause of the altitude error was defective altitude encoding by the intruder.

Slide 10

ADDITIONAL FUNCTIONS OF TCAS TA'S

Several additional functions of TCAS TA's have been demonstrated during testing. First, the comparison of TCAS TA's with visual sightings provides an effective test of the operation of the TCAS equipment. Secondly, TA's assist the pilot in safely making a prompt return to course after RA's are cleared. Thirdly, TA's assist the maintainance of visual contact (ATC provides no TA updates after the pilot has acknowledged that the traffic is in sight). Finally, TCAS advisories provide a temporary substitute for ATC traffic advisories during ground radar outages or when flying outside radar coverage.

Slide 11

VISUAL ACQUISITION RANGES

In comparison to situations with no TA's, automated traffic advisories produce a dramatic increase in visual acquisition capability. This is because they tell the pilot when and in what direction to look for traffic. The resulting effect upon the range of visual acquisition can be seen in the slide. The range at which visual acquisition occurred is shown as a function of closing rate for subject pilot encounters in which the intruder approached from the foward hemisphere. Two fundamental warning modes were tested. The non-bearing mode provided the pilot with a warning sound at a tau of 30 seconds, but did not indicate the bearing of approach. The bearing mode provided a TA with bearing at a tau value of 40 seconds.

Slide 12

VISUAL SEPARATION REGIMES

Four visual separation regimes can be identified: 1) At extreme range visual acquisition is impossible. 2) At long range, visual acquisition is possible, although it may not be obtained immediately. At this range, it is not possible to evaluate the degree of hazard presented by an intruder nor to ascertain the proper direction for an avoidance maneuver. At medium range, it becomes easy to visually acquire and it is usually possible to perceive the existing miss distance and thus infer the proper direction for an avoidance maneuver. At close range, visual acquisition occurs almost instantly and the threat evaluation is usually quite simple.

The time-before-collision at which an intruder enters each regime is dependent upon the closing rate. If the closing rate is such that an avoidance maneuver must begin at long or extreme range, then visual separation becomes highly questionable. One advantage of TCAS resolution advisories is that they allow the pilot to begin the resolution process at these ranges.

Slide 13

TCAS-II AND ATC

In tests that simulated ATC interaction TA's from ATC tended to precede TA's from TCAS by an average of approximately 15 seconds. TCAS TA's are not generally received for aircraft at normal IFR spacings. However, aircraft passing at ± 1000 foot altitude spacings did produce TCAS TA's. This traffic is normally called by ATC in any event.

Pilots indicated that if they received a TA from traffic in an area which they thought ATC was keeping clear for them, they would probably call ATC for consultation.

ATC tended to treat aircraft responding to TCAS RA's in a manner analagous to controlled aircraft maneuvering to avoid visually sighted uncontrolled traffic. That is, the pilot was regarded as acting under his emergency authority and ATC did not attempt to impose ATC control until informed that the TCAS "emergency" had passed. Thus, during the period of response, the TCAS aircraft, assumed complete responsibility for separation from <u>all</u> traffic and TCAS TA enhancement of "see-and-avoid" was especially important.

Slide 14

WORKLOAD IMPACT OF TA'S

One objective of recent tests has been to determine whether TCAS II TA's can produce any undesirable increases in pilot workload. It appears that insofar as TCAS advisories may direct pilot attention to traffic of which he would otherwise be ignorant, they will produce an occasional increase in workload. However, there have been no indications that pilots consider this to constitute an unacceptable or desirable workload element.

When the workload was far below capacity, pilots seemed to welcome any and all TCAS TA's as potentially necessary information which kept then "on top" of the situation. As workload increased, pilots tended to reduce their use of the TA's to a minimum and to use them only when they could decrease workload (e.g. by helping locate traffic that ATC had prompted them to search for).

In most tests to date, the pilot at the controls was asked to both fly the aircraft and use the TCAS display. This produced higher workloads than would be required in an aircraft in which the responsibility for using the TA's is shared among crew members. Study of shared workload procedures will be included in upcoming test flights.

Slide 15

MANEUVERS BASED ON TA DISPLAY

TCAS II is not designed to allow collision avoidance on the basis of TA information alone. Pilot initiated maneuvers based solely upon a TA display might be ineffective and, if vigorous, might invalidate subsequent resolution by creating an accelerating encounter. Hence, tests have carefully examined any tendency of pilots to alter the flight paths of own aircraft in response to the TA display.

In Cessna 421 flights, no tendency has been observed to initiate horizontal avoidance on the basis of TA information alone. However, small altitude changes (typically 200 feet) have been observed in response to the display of approaching co-altitude intruders. These deviations appear to be not so much in anticipation of RA's as due to pilot uneasiness at having less than 200 or 300 feet indicated altitude separation from an approaching intruder. Thus far, these altitude deviations have been uniformly beneficial, providing additional altitude separation at the time of RA issuance. Rates have been quite modest and have never been great enough to cause TCAS tracking problems.

In summary, TA-induced maneuvers have not been found to be a problem. But all such maneuvers should continue to be evaluated in subsequent operational testing.

Slide 16

FUTURE TA TESTING

Additional work is planned to complete the operational evaluation of TCAS TA's:

- Crew procedures will be studied in ground simulators and in actual flight.
- Subject pilot flight tests in jet transport cockpits will be undertaken at the FAA Technical Center.
- Any necessary refinements to the TA logic or to the display design will be incorporated into the design.
- The results of the early operational use of the system by Piedmont Airlines will be carefully scrutinized to verify system performance in actual use.

SLIDE 1

Utility of Traffic Advisory Information

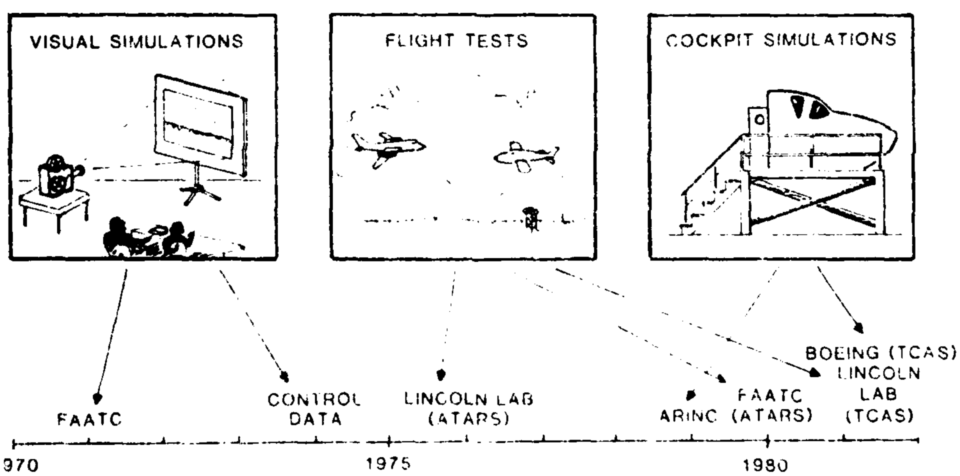
J.W. Andrews, M.I.T. Lincoln Laboratory

Topics To Be Discussed

- Automated TA's – Development History
- Role of TA's in TCAS II
- Test Results
- Future Work

SLIDE 2

Principal Subject Pilot Tests of Automated Traffic Advisories

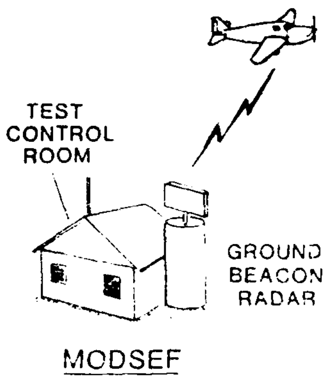


SLIDE 3

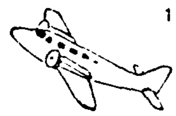
TCAS II Flight Test Operations

At M.I.T. Lincoln Laboratory

INTERCEPTOR
BEECH BONANZA
CREW : 2 Test Pilots



TCAS
CESSNA 421
CREW : 1 Subject Pilot
1 Test Pilot
1 Observer

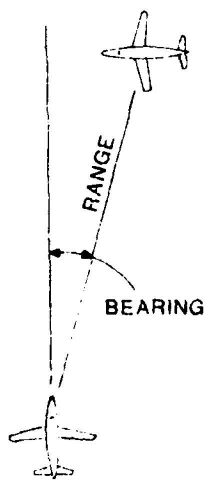


TEST PROCEDURES

- VMC OPERATIONS
- PLANNED INTERCEPTS OF UNINFORMED SUBJECT
- NORMAL OPERATIONS TO/FROM TEST AREA
- SIMULATED ATC
- SIMULATED VOR/DME APPROACHES

SLIDE 4

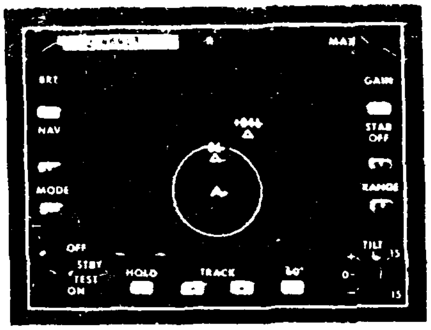
Information Content



- Altitude
- Vertical Motion. Climbing/Descending
- Urgency: Threat/Pre-Threat/Proximity

SLIDE 5

PPI Display Format



SLIDE 6

Uses Of TCAS II TA's

- Stimulate Use of Conventional Separation Techniques
- Allow Correlation of TCAS Advisories With Visually Sighted or ATC-Called Traffic
- Allow Confirmation of Resolution Advisories

SLIDE 7

Stimulation of Conventional Resolution

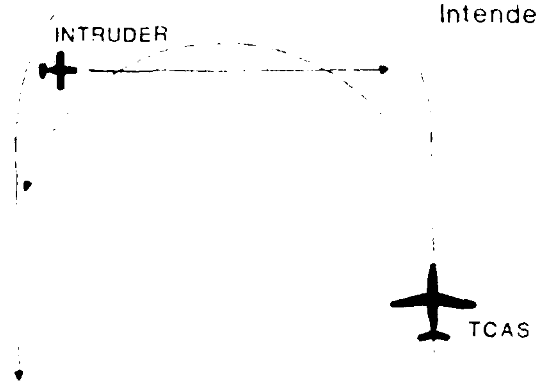
EXAMPLE :

Encounter in
Holding Pattern

19 August 1982

— Path Actually Followed

- - - Path Originally
Intended



On basis of visual and TA, pilot delayed turn.
ATC was notified and approved.

SLIDE 8

Visual/TA Correlation

EXAMPLE : Encounter on 2 Feb 1982

- Slowly closing aircraft visually acquired (without TA), was object of crew concern.
- TCAS TA directed crew attention to fast-closing intruder
- Crew realized first aircraft was non-beac· . (since it was well within proximity range with no TCAS TA)

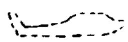
SLIDE 9

Confirmation of Resolution Advisories

EXAMPLE : Encounter with target of opportunity, 9 July 1982

SIGHTED :
200 Ft. Above

TCAS RA : "Climb"



PILOT DECISION :

Maintain Altitude
Maintain Horizontal Separation

REPORTED :
100 Ft Below

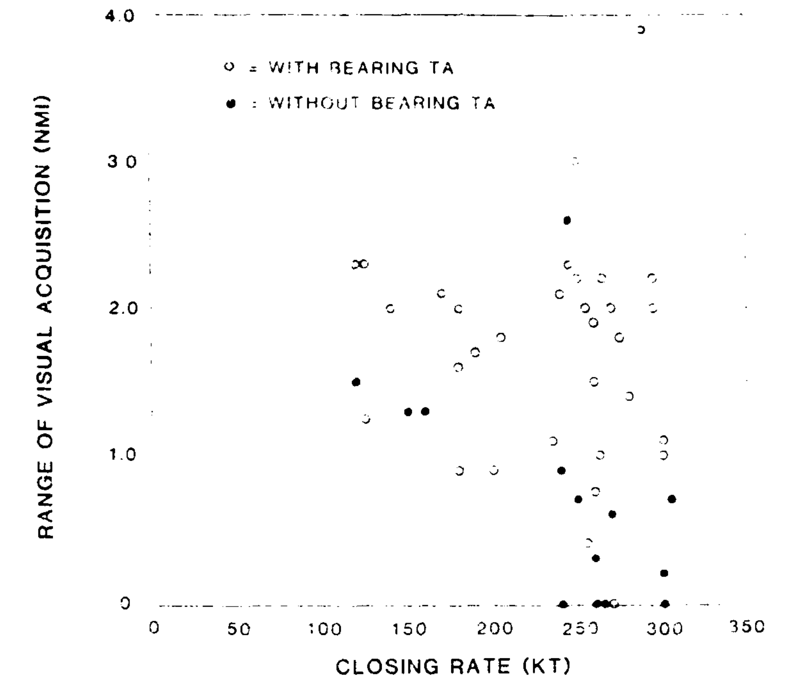
SLIDE 10

Additional Functions of TCAS II Traffic Advisories

- Provide means for monitoring performance of equipment
- Assist recovery after resolution
- Assist in maintaining visual contact with traffic
- Substitute for ATC advisories where no ground radar coverage

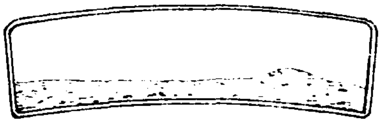
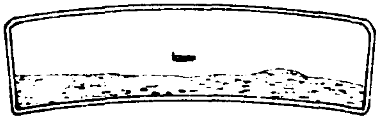
SLIDE 11

Visual Acquisition Ranges



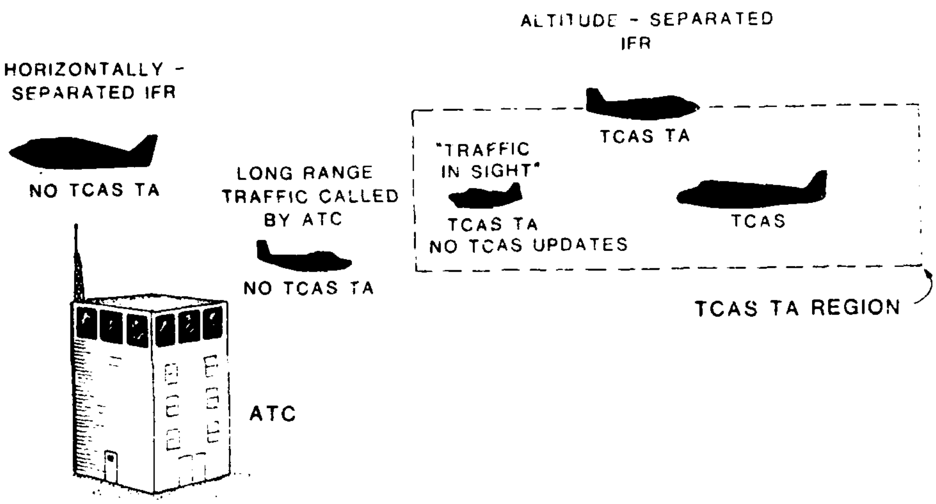
SLIDE 12

VISUAL SEPARATION REGIMES

	VISUAL ACQUISITION	THREAT EVALUATION
EXTREME RANGE 	IMPOSSIBLE	IMPOSSIBLE
LONG RANGE 	POSSIBLE	IMPOSSIBLE
MEDIUM RANGE 	EASY	POSSIBLE
CLOSE RANGE 	EASY	EASY

SLIDE 13

TCAS II And ATC



SLIDE 14

Workload Impact of TCAS TA's

WORKLOAD FACTORS

TA TYPE	CREW RESPONSE	AURAL ALERT
PROXIMITY	OPTIONAL	NO
PRE-THREAT	REQUIRED	YES
THREAT	REQUIRED	YES

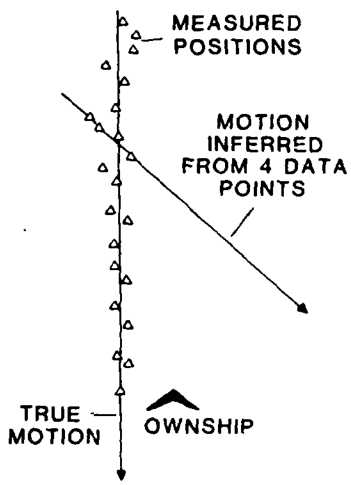
TEST EXPERIENCE

- DEPENDING ON SITUATION, TCAS II TA'S MAY INCREASE OR DECREASE WORKLOAD
- SUBJECTS REPORT SLIGHT NET INCREASE IN WORKLOAD WITH TA'S, BUT FORESEE NO UNACCEPTABLE WORKLOAD IMPACTS

SLIDE 15

Maneuvers Based On TA Display

RELATIVE MOTION IS "NOISY"



TEST CONCERN :

- *Pilots might attempt ineffective avoidance maneuvers based upon TA data alone.*

RESULTS:

- Pilots display no tendency to maneuver horizontally on basis of TA's.
- Small altitude deviations (~200 Ft.) were observed. Thus far, all such deviations were beneficial.

SLIDE 16

Future TA Testing

- *Crew Procedures*
- Jet Transport Test Flights (FAATC)
- TA Logic Refinements
  - Criteria for issuance
  - Parameters
- Analysis of Early Operational Results (Piedmont)

ADDITIONAL PAPERS SUBMITTED

TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM

October 1982

Program Engineering and Maintenance Service
Federal Aviation Administration
Washington, D. C. 20591

1. INTRODUCTION

On June 23, 1981, Federal Aviation Administrator J. Lynn Helms announced the decision to proceed with the implementation of an aircraft separation assurance concept called the Traffic Alert and Collision Avoidance System (TCAS). The concept is based on agency and international development efforts in the areas of beacon-based collision avoidance systems and air-to-air/air-to-ground discrete address communications techniques utilizing Mode S message formats.

The objective of the TCAS approach is to provide a range of separation assurance equipment alternatives that can provide collision protection for the full spectrum of airspace users ranging from small general aviation aircraft to large transport aircraft. TCAS equipments are capable of operating without dependence on ground equipments and will have elements in production by mid-1984.

2. CAPABILITY LEVELS

Various levels of separation assurance will be available from TCAS equipments. The least expensive options, intended for installation in small general aviation aircraft, will simply provide an alert to the pilot indicating that an intruding aircraft is in the near vicinity. No indication of the position (range, altitude, or bearing) of the intruding aircraft would necessarily be given unless the intruder is equipped with TCAS II in which case the crosslink traffic advisory would describe the position of TCAS II as seen from TCAS I. A more sophisticated TCAS unit would be capable of not only providing an alert that an aircraft is nearby but would also indicate the relative position of the intruder by displaying a traffic advisory on an appropriate display in the cockpit. The top-of-the-line TCAS equipments, intended for installation in transport and high performance general aviation aircraft, would not only be capable of providing alerts and traffic advisories but would also compute resolution advisories to indicate which direction the TCAS aircraft should maneuver in order to avoid a collision. TCAS equipment will generate resolution advisories in the vertical plane (climb/descend) and may, depending upon the results of agency development efforts, generate resolution advisories in the horizontal plane (turn right/turn left).

TCAS equipment will generate alerts, traffic advisories and resolution advisories for other TCAS aircraft and for intruders equipped either with today's conventional (ATCRBS) transponder or with a Mode S transponder. In order for resolution advisories to be generated, the intruder must report his barometric altitude through his transponder.

3. TCAS II

TCAS II is a high performance equipment intended for installation in air transport and sophisticated general aviation aircraft. Periodic interrogations transmitted from the TCAS II avionics are responded to by transponders onboard other aircraft thereby permitting TCAS II to determine the position and directions of movement of these aircraft. The position information for proximate aircraft can be displayed to the pilot of the TCAS II aircraft in the form of traffic advisories, and a resolution advisory can be generated when the position and direction of movement of an intruding aircraft indicate that a collision could occur.

If intruding aircraft are not reporting altitude through their transponders, it is not possible to determine reliably which aircraft are potential collision threats and which are not. Therefore, for intruders not equipped with altitude reporting transponders, TCAS II may generate traffic advisories but will not generate resolution advisories.

If the intruding aircraft is equipped with TCAS I avionics, and TCAS II determines that a collision hazard exists, TCAS II will transmit advisory information to the intruder which includes the position of TCAS II with respect to TCAS I. For example, the advisory might convey the following information, "Alert! You are in conflict with a TCAS II aircraft, range 2 nmi, 200 feet below you in your 3 o'clock position."

If the intruding aircraft is equipped with TCAS II, air-to-air communications will ensure that resolution advisories selected in the two aircraft are compatible. For example, one aircraft will elect to climb while the other descends.

A TCAS II aircraft is equipped with the transmitter/receiver used for interrogating nearby aircraft together with the associated computer and display equipments required for threat detection, threat resolution and advisory display. In addition, the aircraft carries an altitude reporting Mode S transponder that provides air-to-air communications with TCAS I and TCAS II aircraft. It is anticipated that high performance avionics of this type would cost \$45,000 to \$50,000 as an integrated unit.

4. TCAS I

TCAS I is a relatively low-performance equipment that permits a small general aviation aircraft to be seen by nearby TCAS II aircraft and to receive limited alert and advisory information about aircraft in its vicinity.

The first alert function inherent in TCAS I equipment is the ability to receive advisory information from TCAS II aircraft as described above. The second alert function is implemented by listening for aircraft transponder transmissions (replies). The replies detected may have been elicited by ground station interrogations (passive TCAS I) or may have resulted from low power interrogations from TCAS I (active TCAS I).

As an option, TCAS I could provide an indication of the bearing of the transponder whose transmission was heard. For example, instead of generating an alarm that says, in effect, "Alert, you have traffic 2 nmi," the alarm says, "Alert, you have traffic 2 nmi at 2 o'clock."

A TCAS I aircraft is equipped with an altitude reporting Mode S transponder that receives the advisory information from TCAS II aircraft and with a receiver for detecting transponder transmissions from proximate aircraft. Display equipments in the TCAS I aircraft would reflect various levels of sophistication appropriate to user needs. Integrated TCAS I avionics units would have costs ranging upwards from \$2500.

5. SUMMARY

Table 1 summarizes separation assurance functions available in TCAS aircraft as a function of the equipments installed on intruder aircraft. Functions shown in parentheses are options. The attachment provides formal descriptions of TCAS I and TCAS II.

TABLE 1

TCAS COLLISION PROTECTION FUNCTIONS

Intruder Equipment	TCAS Equipment: TCAS I	TCAS Equipment: TCAS II
ATCRBS Transponder	Proximity alert (intruder bearing)	(Traffic advisory, no altitude information)
Altitude Reporting ATCRBS Transponder	Proximity alert (altitude filtering, intruder bearing)	Traffic advisory and resolution advisory
Altitude Reporting Mode S Transponder	Proximity alert (altitude filtering, intruder bearing)	Traffic advisory and resolution advisory
TCAS I	Proximity alert (altitude filtering, intruder bearing)	Traffic advisory and resolution advisory
TCAS II	Proximity alert (altitude filtering, intruder bearing) and traffic advisory providing position of TCAS II	Traffic advisory and coordinated resolution advisory

Attachment

TCAS II

MINIMUM REQUIREMENTS

1. Provide collision avoidance protection, independently from the ground ATC system, using vertical maneuvers.

2. Ability to transmit to others (TCAS I and TCAS II equipped aircraft) traffic advisory information (range, relative azimuth, relative bearing where available, differential altitude).

3. Have an integral scanning antenna, or equivalent, with direction-finding accuracy sufficient to present an o'clock display within the TCAS II (own) aircraft, and sufficient accuracy to transmit north-reference relative azimuth advisory information to TCAS I equipped aircraft to present an o'clock display.

The own aircraft display must be altitude-filtered for Mode C-equipped targets, and must display threatening aircraft within designated display range, on a display of the user's choice.

Antenna azimuth receive capability improvements are being developed, in order to achieve unwanted alert reduction and the capability for horizontal maneuvers.

4. TCAS II must provide alert and traffic advisory information to aircraft equipped only with TCAS I, while in the case of two aircraft equipped with TCAS II, coordinated maneuvers will be provided.

5. Ability to operate, with acceptable duty cycle impact on the ground system, in a projected aircraft density environment of 0.30 aircraft per square nautical mile. It is anticipated that TCAS II must be able to operate in an environment of 0.4 aircraft per square nautical mile by the year 2000.

6. The false alarm rate and the missed alarm rate must be acceptable to pilots in everyday operations. In addition, FAA standardized threat detection and resolution logic, or its equivalent, must be used.

7. Like TCAS I, it will have an integral transponder capable of operating on Modes A, C, and S (with surveillance and Comm A, B, and C format capabilities to permit working compatibly with the current and evolving ATC system using Mode S signal formats).

8. A sensitivity adjustment must be provided, independent of the ground ATC system, and must automatically reset to an appropriate level in the event of power interruption.

Note: The system design is based on the requirement that TCAS operation must not cause degradation of ground system performance (round reliability) by more than 2 percent. This will require an adaptive interrogation scheme or equivalent to reduce interference with the ground system.

TCAS I

MINIMUM REQUIREMENTS

1. An integral transponder capable of operating on Modes, A, C, and S (with surveillance and Comm A, B, and C format capabilities to permit working compatibly with the current and evolving ground ATC system using Mode S signal formats).

2. Periodic Mode S squitter transmissions on 1090 MHz.

3. Ability to receive and display traffic advisory information (range, relative azimuth which can be converted to relative bearing, relative bearing if available, differential altitude) from TCAS II equipped aircraft.

4. Ability to receive sensitivity-dependent, non-altitude-filtered proximity information from ATCRBS transponders within ATCRBS or SSR Mode S ground station coverage.

5. Ability to receive sensitivity-dependent, altitude-filtered proximity information from Mode S transmissions generated by other TCAS I and Mode S transponders in all airspace.

6. Manual sensitivity adjustment must be provided, independent of the ground ATC system, and must automatically reset to an appropriate level in the event of power interruption.

ADDITIONAL CAPABILITIES

1. Ability to altitude sort sensitivity-dependent information on ATCRBS transponder-equipped aircraft within ATCRBS or Mode S ground station coverage.

2. A direction finding antenna to provide simple clock position of threats (accuracy on the order of ± 8 degrees).

PRELIMINARY SUMMARY

OF

PHASE I PIEDMONT IN-SERVICE EVALUATION

OF TCAS II

TOM BERRY
ARINC RESEARCH CORP.

TOM WILLIAMSON
FEDERAL AVIATION ADMINISTRATION

OCTOBER 12, 1982

INTRODUCTION

On November 4, 1981, the first of two developmental models of a Traffic Alert and Collision Avoidance System (TCAS) was approved by the FAA Southern Region for operation aboard Piedmont Airlines Boeing 727 aircraft during normal passenger carrying operations. This approval was in the form of a Supplemental Type Certificate issued with the restriction that the system was to be used for collection of data on the operational performance of the TCAS and not to be used by the flight crews.

Over the following five months data was collected by ARINC Research Corp., on the operational performance of the TCAS during 928 hours of flight time. This data was generated from two sources, (1) A data recording system aboard the test aircraft that recorded quantitative data generated by the TCAS each time the system detected a potential conflict and activated the system displays, and (2) Qualitative comments on the system performance and utility of TCAS, prepared by cockpit observers who were skilled in jet transport operations.

TEST DESCRIPTIONS

The system tested was developed by Dalmo Victor Operations of Bell Aerospace Textron under contract to the Federal Aviation Administration (FAA). It consisted of an RF/Processor unit installed in the aircraft electronics compartment,
two direction finding antennas mounted on the top and bottom of the aircraft, a control/display unit located in the flight observer area of the cockpit (outside the view of the flight crew), and an instantaneous vertical speed indicator (modified to display aircraft maneuver advisories) mounted atop the control/display unit In addition, a time-of-day clock and digital tape recorder were installed in the electronics compartment of the aircraft. These two items were used as test instrumentation and would not be part of an operational system.

AD-A123 037 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) SYMPOSIUM (3RD) OCTOBER 12-13 1982(U) FEDERAL AVIATION ADMINISTRATION WASHINGTON DC SYSTEMS RESEARC.. 1982

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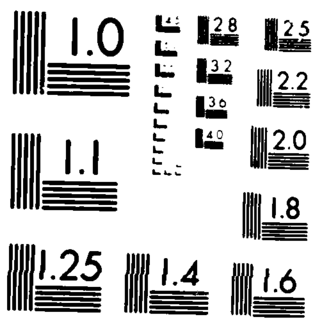

1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

The Dalmo Victor system implemented the Lincoln Laboratory surveillance design and the collision avoidance logic developed for the FAA by MITRE Corporation. The logic examines the range, range rate, altitude, and altitude closure rate to define a conflict situation. When a conflict is determined the logic develops a vertical escape maneuver to resolve the conflict. The system has no capability for computing horizontal escape maneuvers.

The aircraft flew a normal route and was indistinguishable from any other Piedmont B-727 to air traffic controllers who handled the flights. The aircraft was not locked into any specific routing and at some time flew every segment of the Piedmont B-727 route structure.

While the first flight with TCAS aboard was made on November 4, 1981, the majority of the data was recorded during January, February, and March, 1982. Cockpit observers were aboard approximately one-third of the data flights.

RESULTS

During the 982 hours logged, 329 traffic advisories were experienced and 32 resolution advisories occurred. These events occurred during normal airline operations and did not represent ATC system errors. Forty-five percent (148) of the traffic advisories and twenty-two percent (7) of the resolution advisories were generated by aircraft on the ground at the time of the event. A technique to suppress these advisories against on-ground aircraft has been developed and will be implemented for the Phase II evaluation.

Traffic advisories (with no subsequent resolution advisories) on airborne aircraft averaged one each 5.13 flight hours. The majority of the observed traffic advisories on airborne aircraft (29 of 50) were caused by other air carrier aircraft. In 16 cases (32%) the observers were unable to determine the type of the other aircraft. Only 3 (6%) of the 50 observed traffic advisories were identified as general aviation type aircraft. The remaining two incidents were caused by a helicopter and a commuter aircraft.

Resolution advisories on airborne aircraft averaged one each 37.15 hours. The majority of the observed resolution advisories against airborne aircraft (4 of 8) were caused by general aviation aircraft. The majority of these conflicts occurred near an airport with both aircraft operating in Visual Meterological Conditions (VMC), with visual contact, and under control of the appropriate ATC facility.

Most traffic advisories and resolution advisories against airborne aircraft occurred below 10,000 feet Mean Sea Level (MSL). In 62% of the incidents, the other aircraft was more than 500 feet and less than 1500 feet above or below the test aircraft at the time the advisory was started. Only 21% of the advisories were started with less than 500 feet vertical separation between the two aircraft. Most of the advisories (81%) were caused by aircraft forward ($\pm$ 90° relative bearing) of the TCAS aircraft at the time of advisory. There were no recorded cases when an advisory was caused by another aircraft overtaking the test aircraft.

No Vertical Speed Minimum (VSM) were recorded as the first advisory selected by the TCAS. Seventy-five percent (75%) of the initial resolution advisories against airborne aircraft were Vertical Speed Limits (VSL) or negative advisories. Only 6 of the 25 resolution advisories generated against airborne aircraft included positive advisories.

Of more interest is the frequency of corrective advisories, that is, those requiring an alteration in flight path. Eight of the resolution advisories would definitely have required deviation from the recorded flight path, while 7 of the resolution advisories might have required some change in flight path, depending on the intentions of the pilot at the time of the advisory. For example, if a "DO NOT CLIMB" advisory was displayed at a time when the climb rate was decreasing in response to pilot initiation of a level-off, there would be no requirement for the TCAS aircraft to deviate from its planned flight path. Ten of the resolution advisories were clearly not corrective i e., they did not require deviation from the current flight path. Based on the data recorded during this evaluation, an average air carrier flight might expect to see one corrective TCAS advisory per month.

The average resolution advisory sequence observed during the evaluation consisted of approximately 14 seconds of precursor traffic advisory, 10 seconds of resolution advisory, and 26 seconds of post resolution advisory traffic information. These are statistical averages and vary considerably form incident to incident. They are based on data collected with no response by the TCAS aircraft and will change when the aircraft initiates response action to resolution advisories.

The cockpit observers felt that improvements to the desensitization scheme were required to eliminate advisories from aircraft that were on the ground. With this exception, they felt that the TCAS performed its task with no other unacceptable impact on flight operations. The cockpit observers were not unanimous in their endorsement of traffic advisory information. The majority of the observers felt that traffic position information provided desirable information to the flight crew that would be useful in evaluating the conflict situation and moderating the response maneuver. The comments of the observers indicate that advisory rates against airborne aircraft appear to be well within the acceptable range.

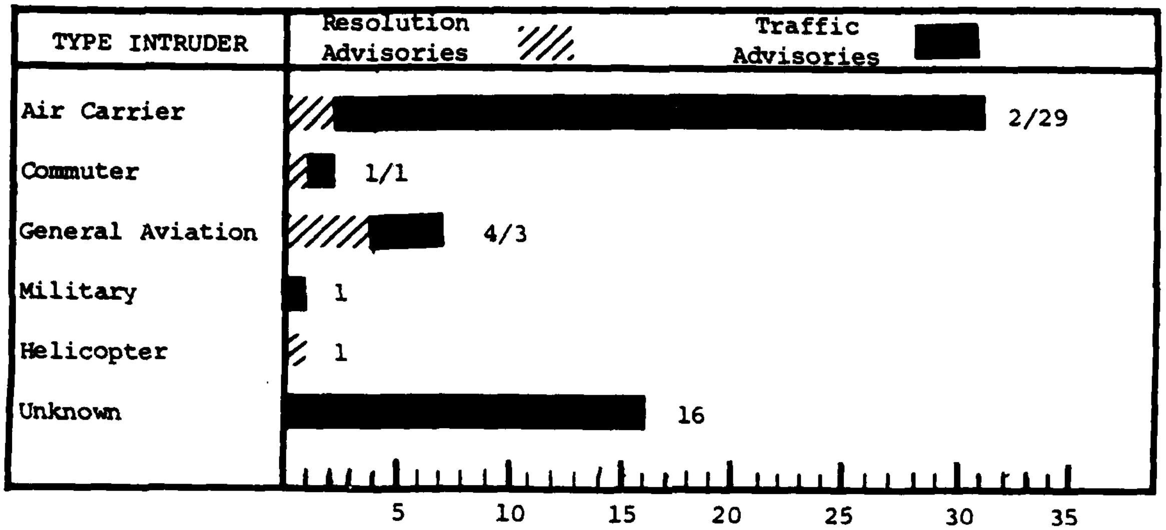


Figure 1. TYPE OF INTRUDER
(OBSERVED ADVISORIES ONLY)

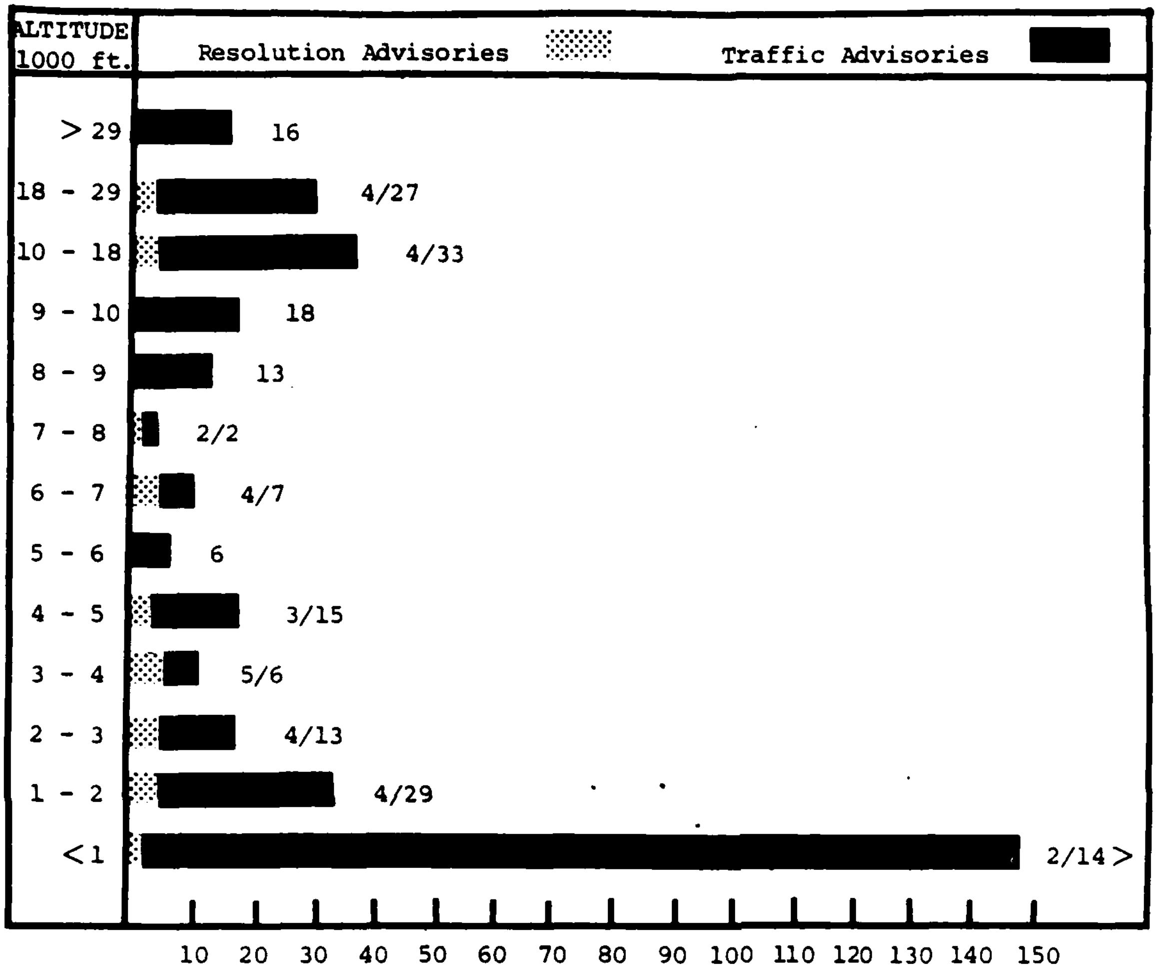


Figure 2. ALTITUDE OF OWN AIRCRAFT AT TIME OF FIRST ADVISORY

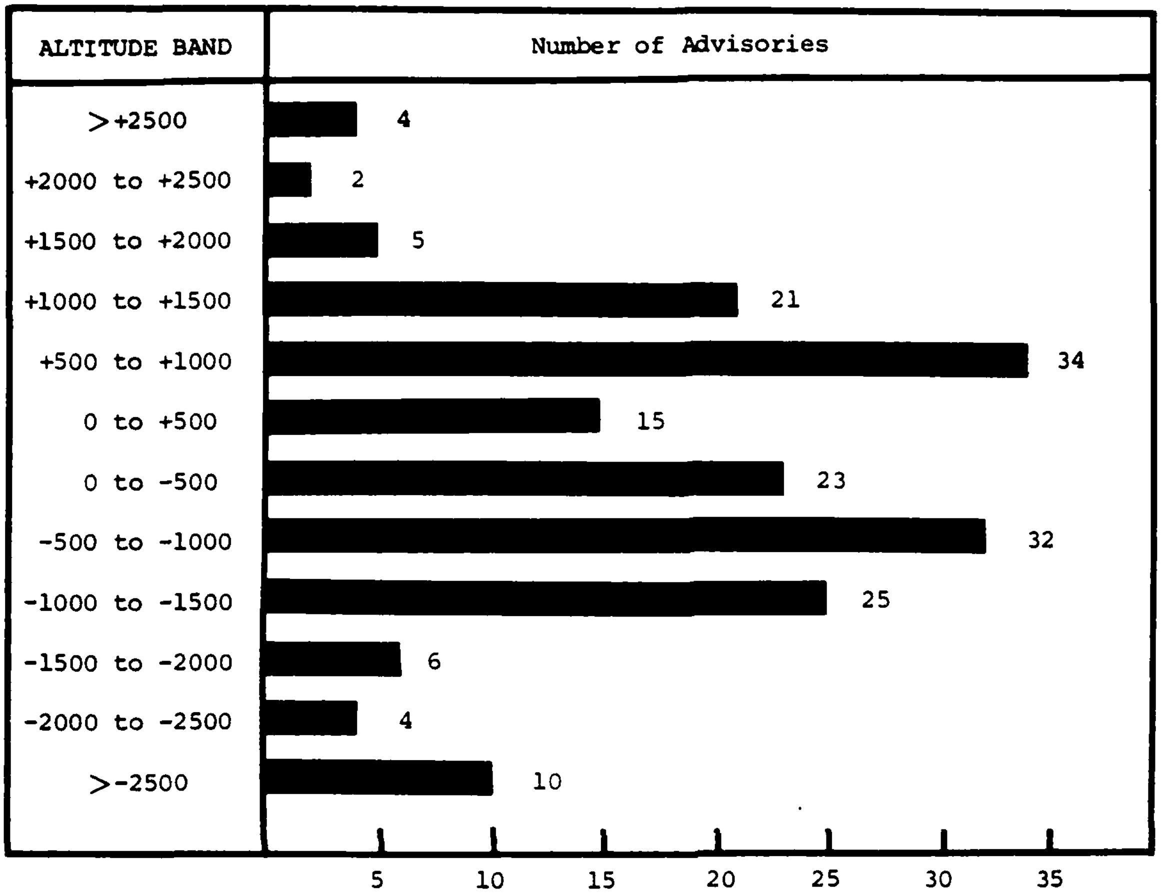


Figure 3. TRAFFIC ADVISORIES BY RELATIVE ALTITUDE (AIRBORNE TRAFFIC ONLY)

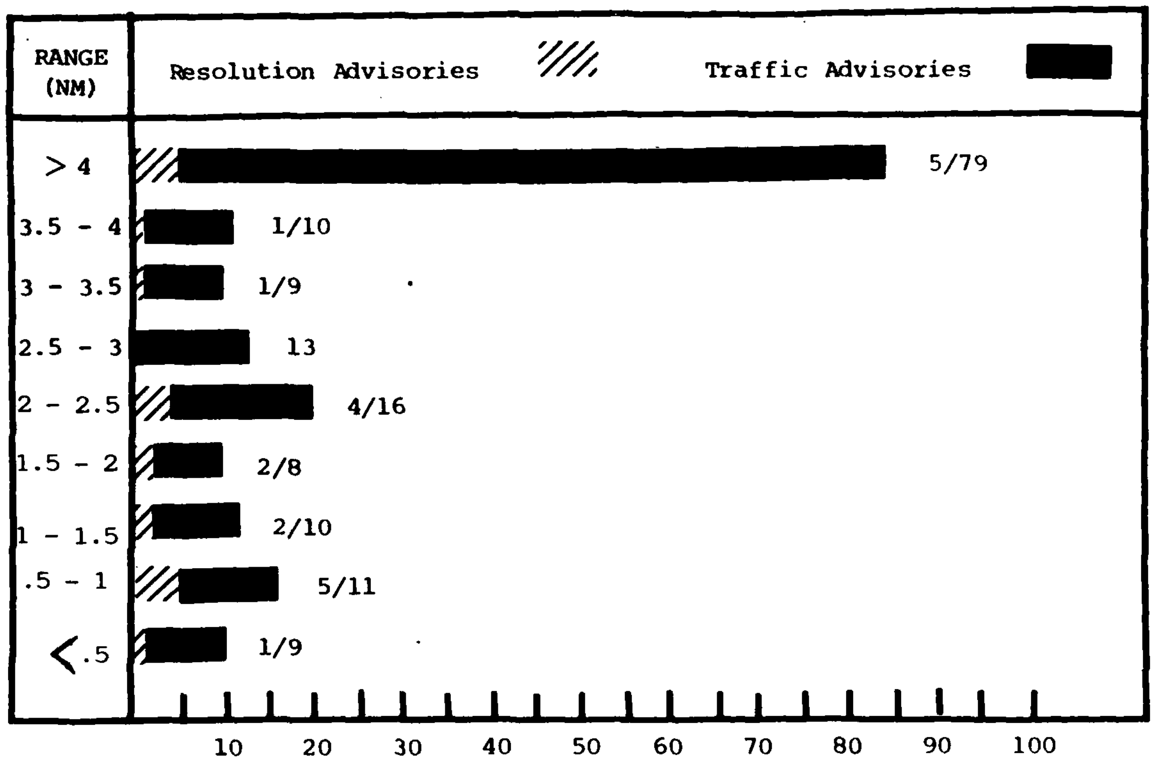


Figure 4. ADVISORIES BY RANGE
(AIRBORNE AIRCRAFT)

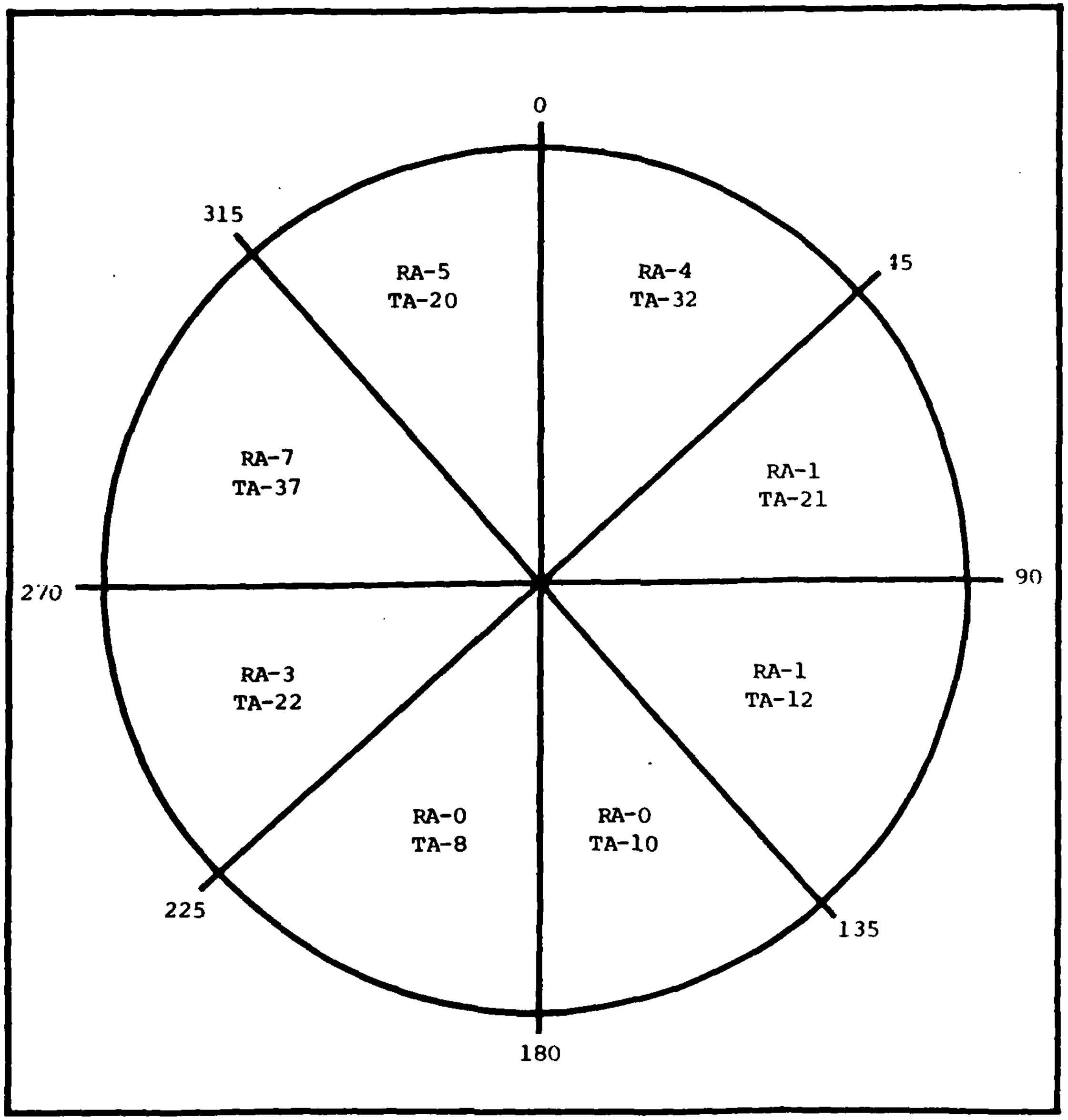


Figure 5. ADVISORIES BY INITIAL BEARING
(AIRBORNE WITH BEARING DATA)

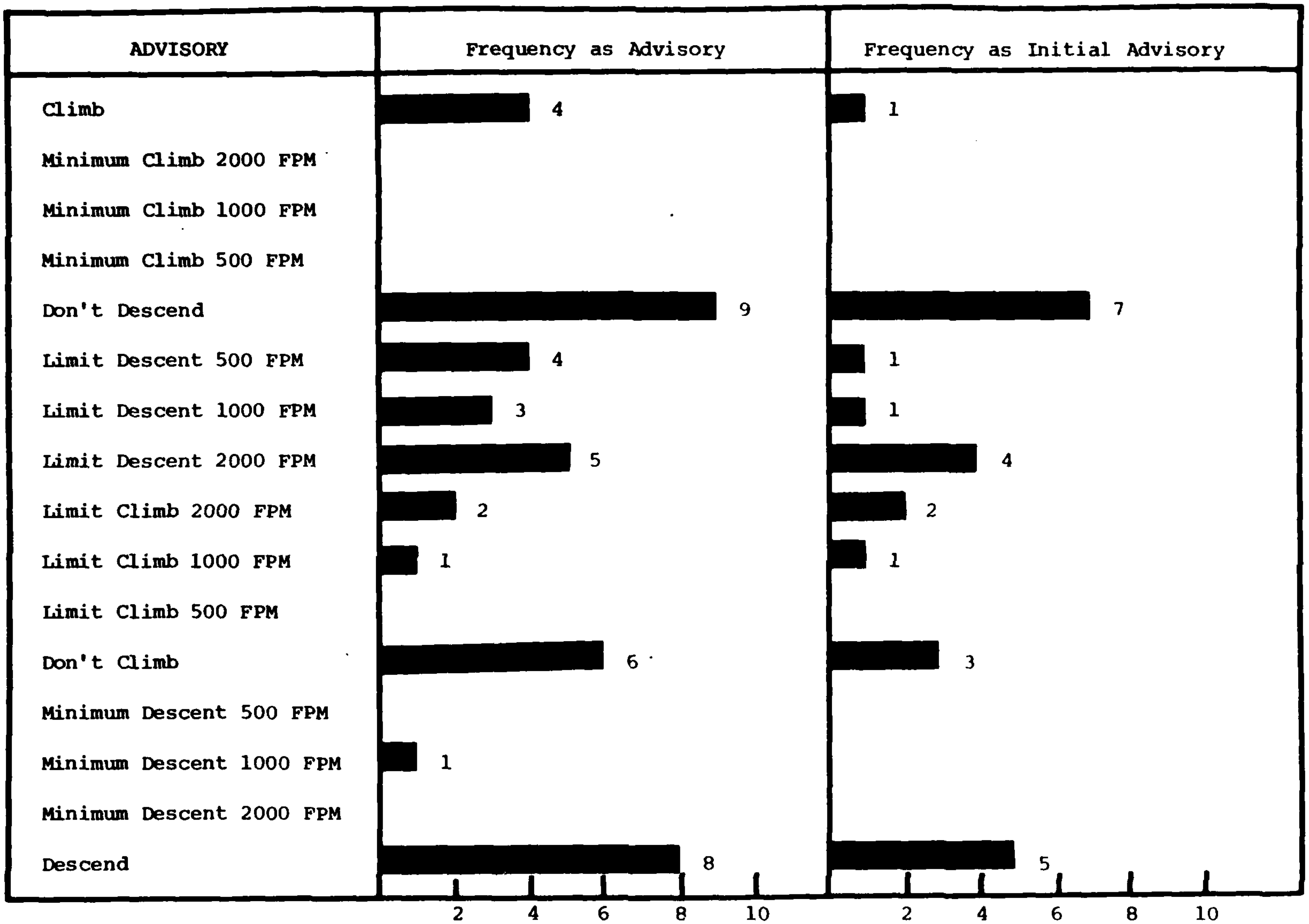


Figure 6. RESOLUTION ADVISORY FREQUENCIES
(AIRBORNE AIRCRAFT)

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave. S.W.
Washington, D.C. 20591

SUBJ: Summary of Dalmo Victor and Lincoln Laboratory
PWI Bearing Performance

This paper summarizes the results of bearing accuracy and tracking tests performed using the Lincoln Laboratory TCAS Experimental Unit (TEU) and the Dalmo Victor omni directional TCAS. The TEU data which is presented was obtained from Lincoln Laboratory flight tests in the Boston area. The TEU bearing tests were also conducted at the FAA Technical Center and are being analyzed and these results will be available in December 1982.

Dalmo Victor omni directional TCAS bearing data was obtained from anechoic chamber tests at Dalmo Victor; static tests at FAA Technical Center, and flight tests at FAA Technical Center. Additionally, a bearing track from a Piedmont flight during which a resolution advisory occurred is also shown.

LINCOLN LABORATORY TEU BEARING PERFORMANCE

There are two distinct types of errors that affect the accuracy of the airborne direction finding system: systematic or repeatable errors and random or unpredictable errors. Three types of systematic errors have been identified. Bias errors occur due to inaccurate initial calibration or to differential variations in the insertion phase of phase-matched transmission lines or other components. With sufficient care, these errors can be kept insignificant relative to the other systematic errors. A second source of systematic error is the inherent ripple in the phase transfer function resulting from the use of discrete antenna elements. This error component increases due to geometrical distoration as the elevation angle of the reply emmitter is increase. For small elevation angles, the ripple is roughly sinusoidal with a peak deviation of about 10°.

The most significant source of systematic error is scattering from the surface of the TCAS aircraft. The magnitude of the angle error due to airframe scattering can be estimated from antenna pattern measurements. Scattering effects on small aircraft will result in peak bearing errors as large as 20° in the forward direction and 40° in the aft direction. The peak errors for angle-of-arrival antennas installed on larger air carrier aircraft should be less than half these values.

Random errors arise from receiver noise, fruit, and multipath. The maximum visual range for a target is about 3 or 4 miles. A reply from an aircraft at this range results in a nominal signal to thermal noise ratio of about 40 dB. The resulting contribution to the phase error for a single pulse is about 1°. This is further reduced by averaging and tracking. In low-density airspace the effects of fruit are about the same as receiver noise. Multipath signals are the most significant sources of random errors. A multipath echo received just below MTL will cause 6° RMS errors in the angle estimates for single pulses. For ATCRBS replies most multipath echoes received above MTL will be detected by the garble sensing algorithms in the ATCRBS reply processor and rejected. Another significant source of random error in the experimental system is the automatic diversity antenna switching in the TCAS unit. This converts the bias differences between two antennas to apparent abrupt measurement errors. This error source does not exist if a single AOA antenna is mounted on top of the aircraft.

The flight test results obtained with the Lincoln Laboratory TEU are summarized in Table 1. The data shows that the average bearing error was about 10°: PWI bearing tracks for an ATCRBS and Mode S target, are shown in Figures 1 and 2, respectively.

DALMO VICTOR OMNI TCAS BEARING PERFORMANCE

The Dalmo Victor omni directional TCAS unit has been extensively tested at Dalmo Victor, the FAA Technical Center, and on two Piedmont B-727 aircraft during revenue flights. A comparison of the data from each source has been performed and provides an indication of the effect that aircraft structure has on bearing accuracy and tracking performance.

At the FAA Technical Center static ground tests were performed with the antenna mounted on the aircraft, followed by flight tests with target aircraft. During the flight, the relative in-flight geometry was varied in order to provide an evaluation of composite performance at different azimuth and elevation angles.

ANECHOIC CHAMBER TESTS

The data taken during anechoic chamber tests at Dalmo Victor are shown in Figures 3, 4, and 5 for elevation angeles of 0°, 15°, and -15°, respectively. The RMS bearing error, as a function of azimuth angle, is presented in Table 2. The anechoic chamber data shows a large error lobe with an RMS of 13.41° centered at about 320° (i.e., 40° left of the forward position). When the elevation angle of the target is below the ground plane, the overall bearing error increases significantly. In the forward quadrant (i.e., 22.50° on either side of the nose) the RMS error increases from 6.26° at zero degrees elevations to 21.3° at -15° elevation. The RMS anechoic chamber data for the 0° elevation case is also shown in Figure 6.

STATIC TEST DATA

Static test data was obtained at the FAA Technical Center using a mobile van with a transponder mounted on a mast. The van was placed at several azimuth points and bearing measurements were made with either a ATCRBS or Mode S transponder as a target. The results of the static test are shown in Table 2 and Figure 6. A comparison of the anechoic chamber data and the ATCRBS static test data reveals that the errors are about the same magnitude and follow the same trend. Another interesting observation is that there is no detectable correlation between the bearing error and the azimuth position of the aircraft wind and tail structures.

FLIGHT TEST DATA

Flight tests were conducted with flight profiles which were selected to determine the effect of azimuth and elevation angles on bearing accuracy. The true relative position of the TCAS and target aircraft was obtained using the FAA Technical Center Nike tracking network.

The flight sequence which provides data of particular interest was the azimuth orbit flights. The RMS error for this flight profile was computed separately for the top and bottom antennas and is shown in Table 2. The elevation angle which the target was at during the test is also listed and shows that negative elevation angles result in larger errors due to the aircraft structure. The RMS error for the top antenna is also plotted in Figure 6 and indicates that the bearing errors during the flight test are larger than those seen during both anechoic chamber and static tests.

An RMS error of 14.2° occurs in the forward region, which is larger than expected. It has been concluded that the negative elevation angle (i.e., -50°) of the target when it was in the forward sector is responsible for the large error. This conclusion is further substantiated by comparing the anechoic chamber errors at elevation angles below the ground plane (i.e., 21.3° RMS). The flight data also shows that in the tail sector the RMS error also increased (17.6° RMS). Since the target was at +3° in the tail sector the aircraft structure caused the RMS error of the bottom antenna to also be larger (i.e., 19.3°).

PIEDMONT BEARING TRACK

The bearing track of an intruder which was observed during a Piedmont Airlines flight with omni TCAS is shown in Figure 7. The bearing track for this encounter is similar to those obtained during flight tests with the Lincoln Laboratory unit (i.e., Figure 1).

CONCLUSION

The objective of the bearing tests which were performed with the Lincoln Laboratory and Dalmo Victor TCAS units was to determine if the bearing accuracy and bearing track performance was sufficient to support a PWI function. The overall accuracy obtained using all the FAA Technical Center flight test data (i.e., all profiles) shows that the RMS error is 15° or less. Since o'clock accuracy has been the guidelines for PWI performance of both the Dalmo Victor and Lincoln Laboratory TCAS units support the PWI functions.

PLAN-POSITION DISPLAY FOR ENCOUNTER WITH ATCRBS TARGET

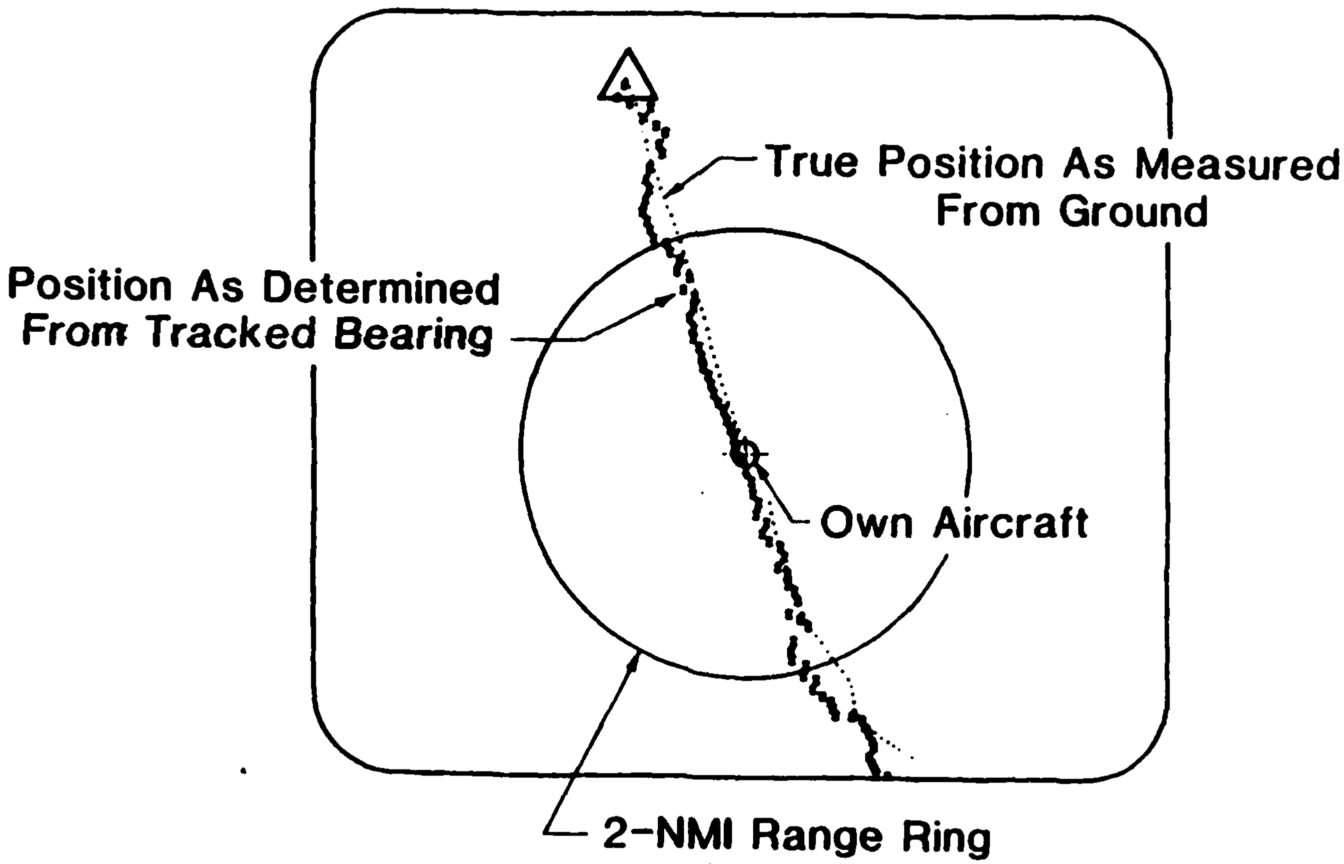


FIGURE 1

PLAN-POSITION DISPLAY FOR ENCOUNTER WITH MODE S TARGET

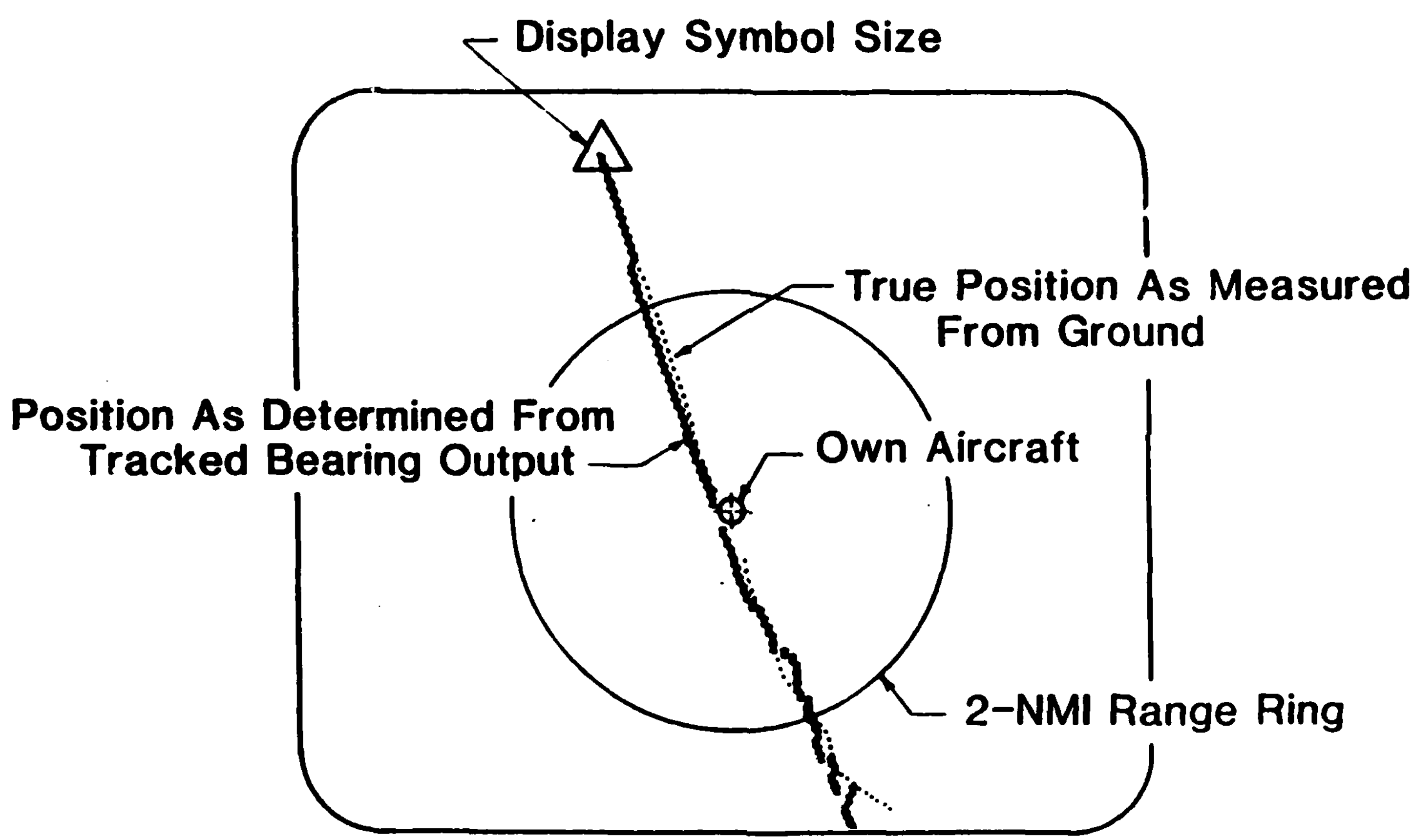
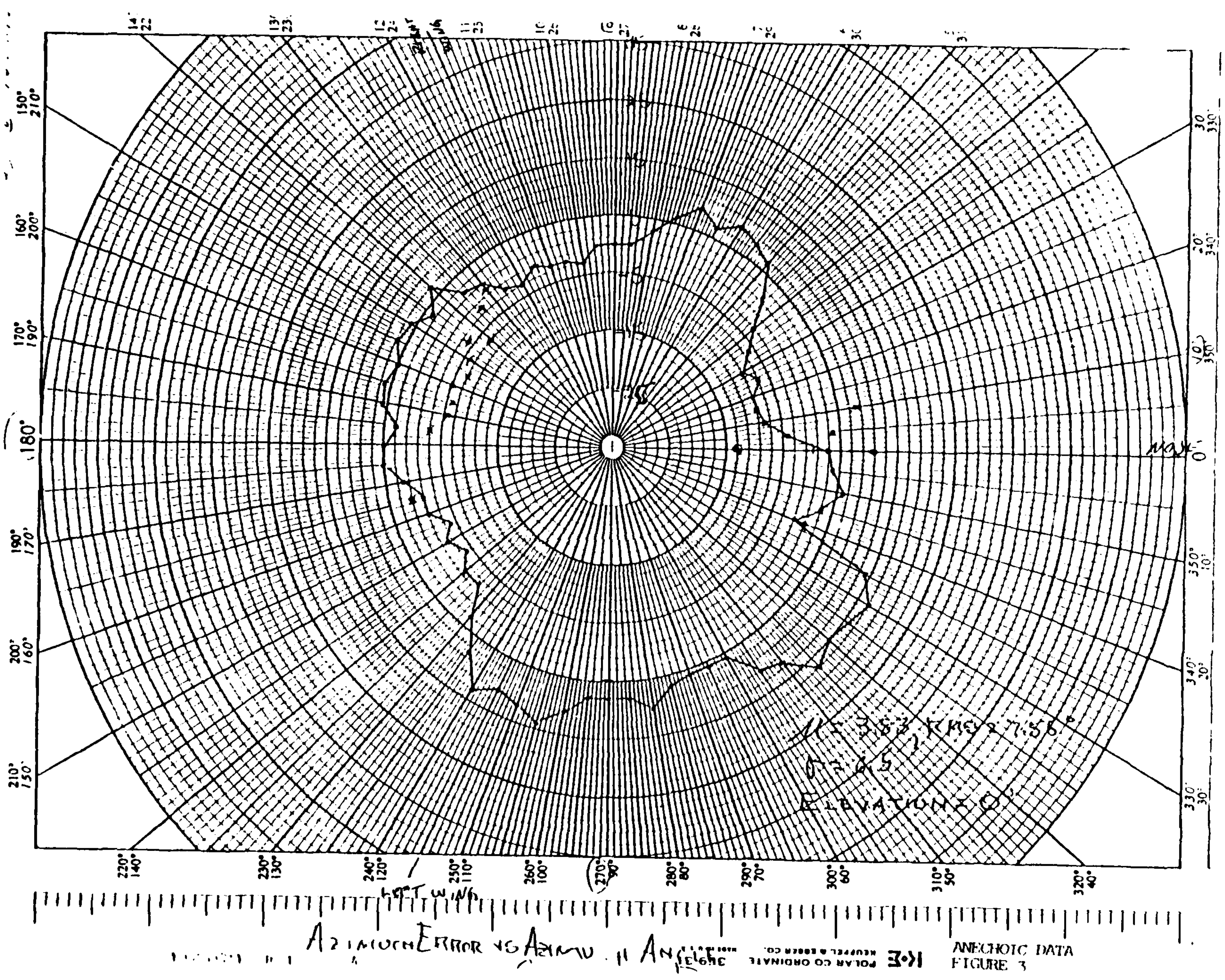


FIGURE 2



ANECHOIC DATA
FIGURE 3

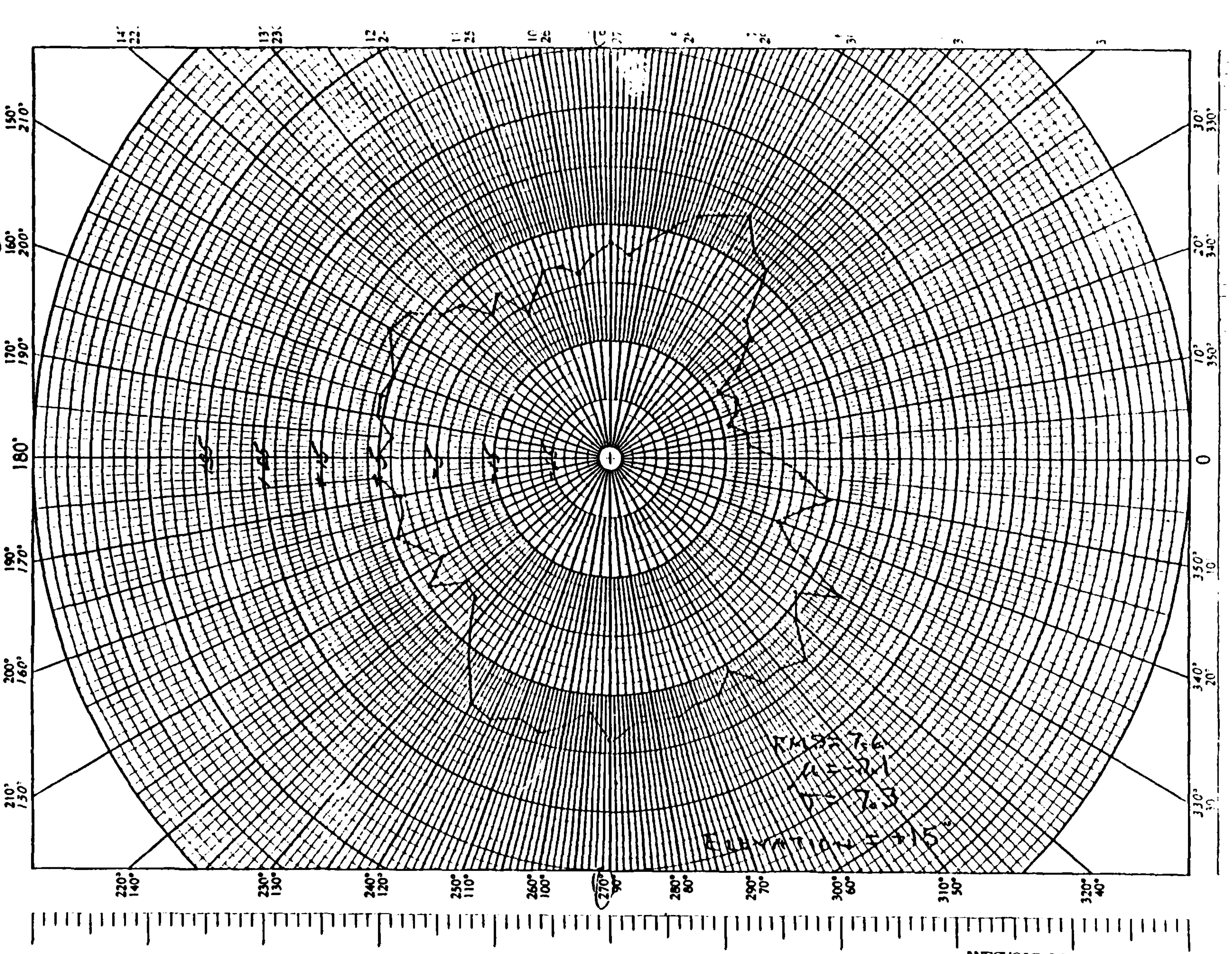


FIGURE B-2. AOA ERROR VS AZIMUTH ANGLE

ANECHOIC DATA
FIGURE 4

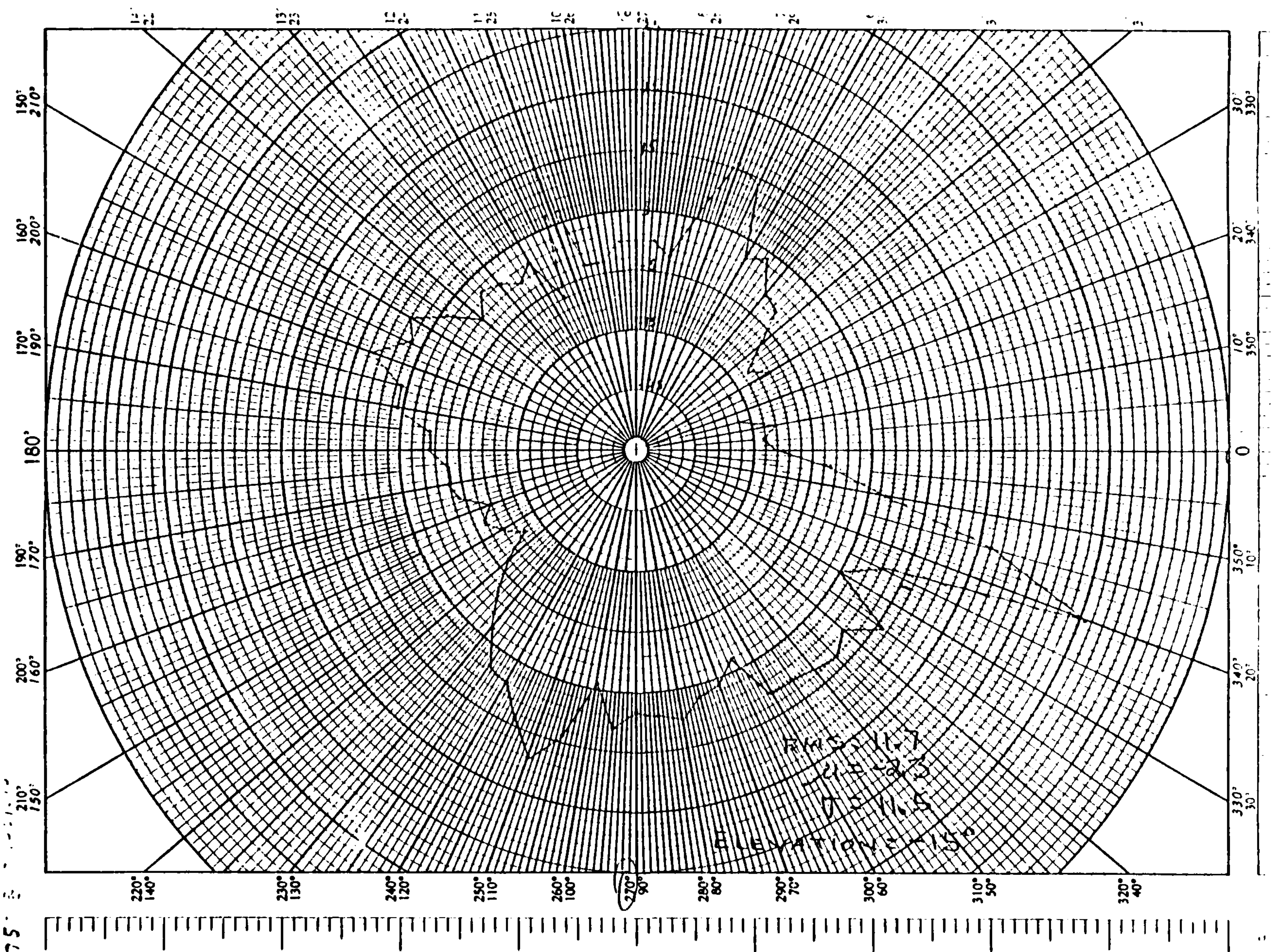


FIGURE 8-3. AOA ERROR VS AZ ANGLE

ANECHOIC DATA
FIGURE 5

BEE 20x20 TO INCH

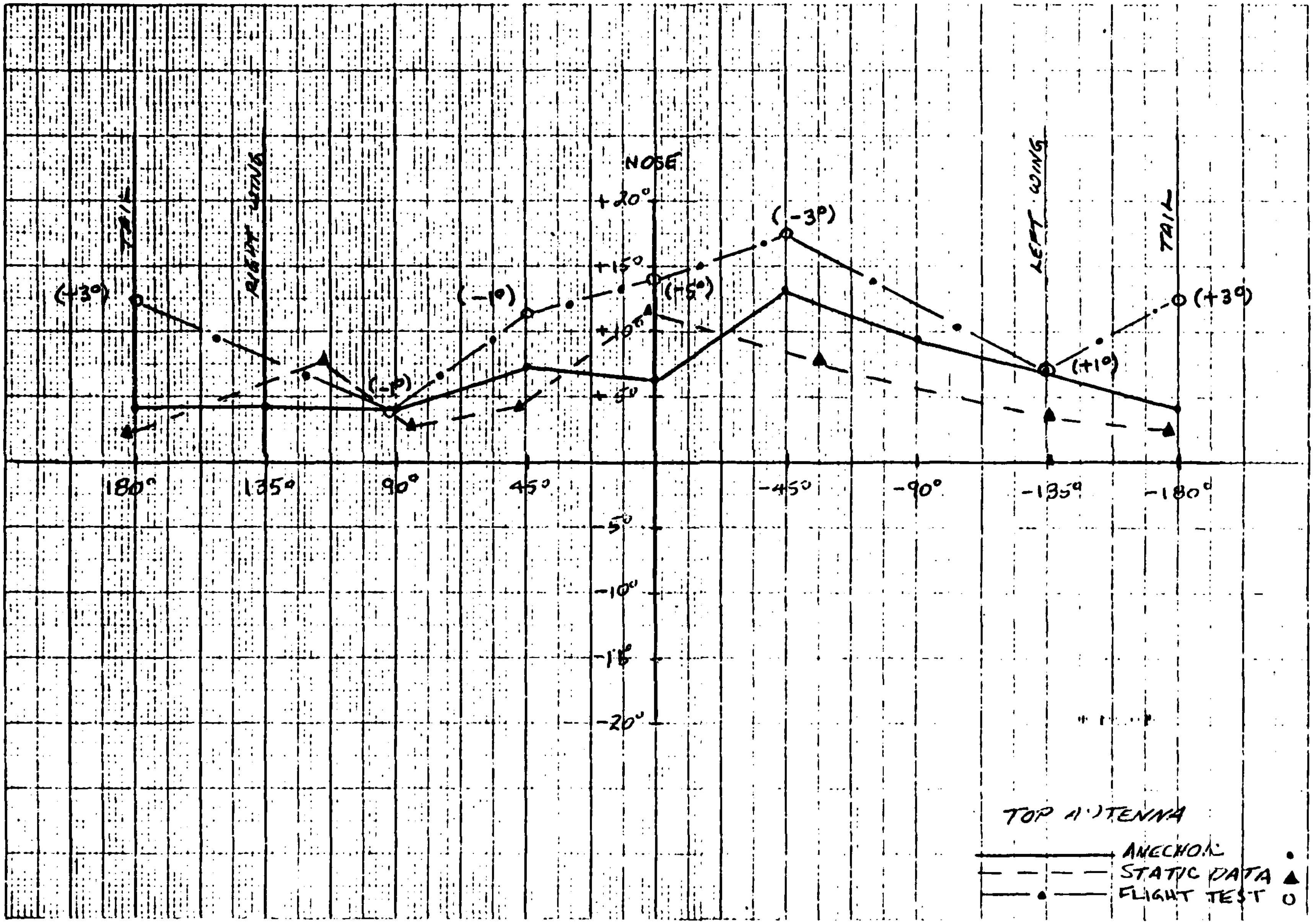


FIGURE 6

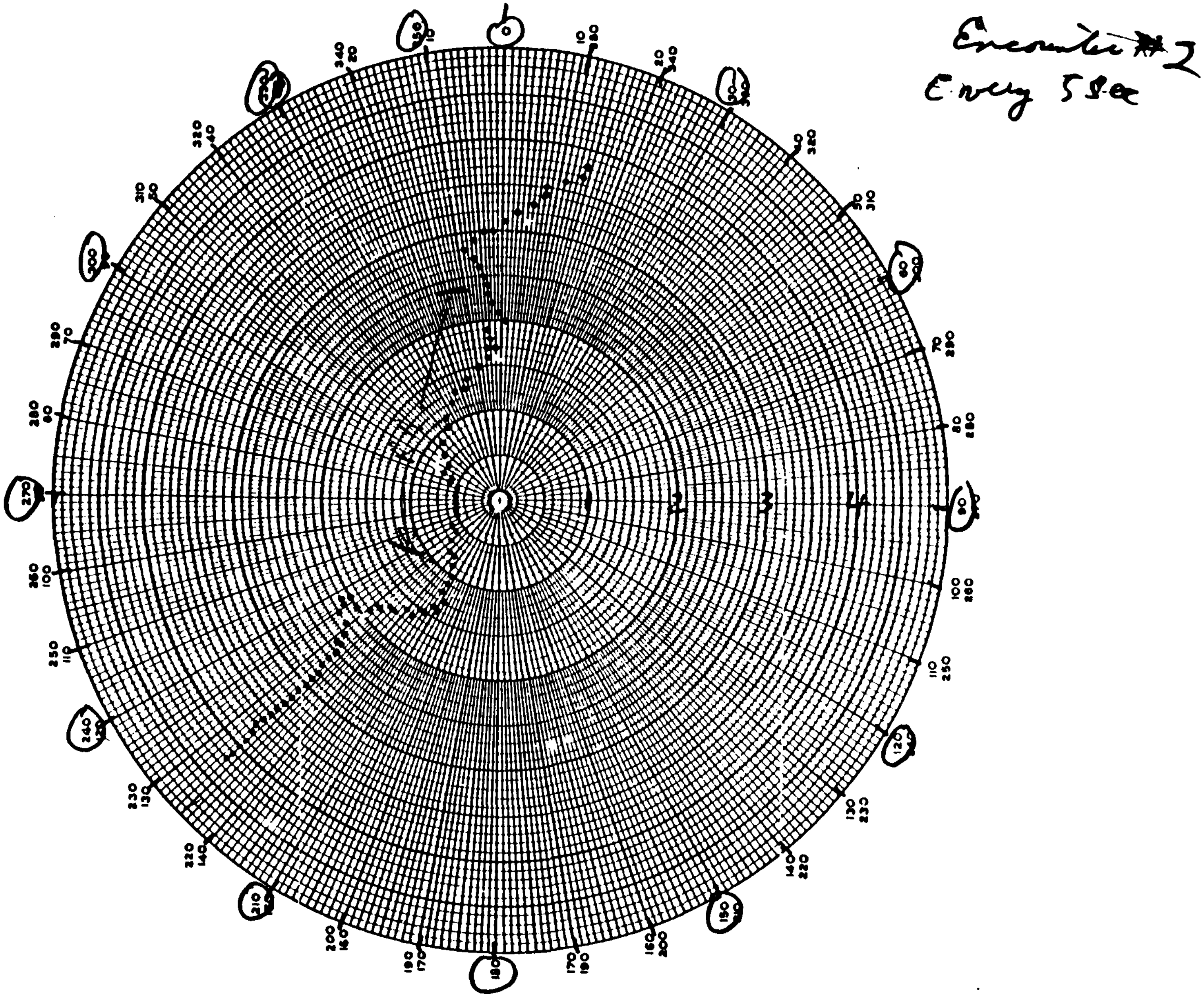


FIGURE 7

AOA ENGINEERING EVALUATION - FLIGHT TEST RESULTS

- AVERAGE BEARING ERROR

	ATCRBS MODE-C	MODE-S
TOP ANTENNA REPLIES	8.9^0	9.6^0
BOTTOM ANTENNA REPLIES	11.1^0	9.5^0
CAS TRACKS	7.8^0	8.8^0

IMPROVEMENT IN BEARING ACCURACY DUE TO MODE-C TRACKING - 22%

IMPROVEMENT IN BEARING ACCURACY DUE TO MODE-S TRACKING - 8%

- PROBABILITY OF MAKING A BEARING ESTIMATE ON A RECEIVED REPLY

  ATCRBS MODE-C - 93%

  ATCRBS NON-MODE-C - 77%

  MODE-S - 100% (BY DEFINITION)

TABLE 1

COMPARATIVE ANECHOIC, STATIC AND FLIGHT TEST BEARING ACCURACY

ANECHOIC CHAMBER		STATIC FAA TECH CENTER (ATCRBS)	FAA TECH CENTER FLIGHT DATA (ATCRBS)		
	RMS(0° Elev)	RMS	ELEVATION ANGLE	RMS(TOP)	RMS(BOTTOM)
0° ± 22.5°	6.26°	11.68°	-5°	14.2°	-----
45° ± 22.5°	7.26°	4.47°	-1°	11.6°	5.8°
90° + 22.5°	4.05°	3.0°	-1°	4.3°	6.8°
135° ± 22.5°	4.42°	8.0°	-----	-----	-----
180° ± 22.5°	4.33°	2.85°	+3°	12.5°	19.1°
225° ± 22.5°	7.15°	3.68°	+1°	7.2°	10.4°
270° ± 22.5°	9.66°	-----	-2°	----	4.2°
315° ± 22.5°	13.41°	7.8°	-3°	17.6°	8.2°

TABLE 2

ATTENDEES
TCAS Symposium

Michel Alban	Thomson-CSF
Ken Alderman	Forest Service - USDA
William D. Alexander	United Airlines
Chris Allen	Texas Int'l Airlines
John Andrews	MIT/Lincoln Lab
G. S. Aitken	Transport Canada
Ward J. Baker	Air Line Pilots Assoc.
William F. Baltra	Matsushita Avionics Systems
Harold W. Becker	FAA (AAT-220)
Arthur R. Beier	FAA
Thomas P. Berry	ARINC Research Corp.
Michel Best	Air France
Barry R. Billman	FAA
Richard L. Bowers	Air Transport Assoc.
Leonard L. Bosin	FAA
Valerie Boykin	MITRE Corp.
Robert G. Buley	Republic Airlines
Henri Bulterman	MITRE Corp.
Ken Byram	FAA
Robert A. Byrd	Delta Airlines
John L. Cataldo	MIT Lincoln Laboratory
Frank S. Chandler	Dalmo Victor
Wendie F. Chapman	FAA
Weldon B. Clark	Trans World Airlines
B. R. Climie	ARINC Research Corp.
D. P. Coleman	IDC
Bela Collins	MITRE Corp.
Walter Cronkhite	FAA
Peter Cuneo	FAA
William W. Edmunds	Air Line Pilots Assoc.
G. Falsitt	FAA
Fatus	MITRE Corp.
David H. Featherstone	ARINC
Harold H. Fink	ARINC
Robert D. Force	Boeing
Dr. Peter Form	Technical University Braun.
Andres Fragra	Eastern Airlines
William J. Fraser	Martin Marietta
Robert A. Frazier	FAA
W. C. Fuchs	RTCA
R. H. Fuller	Cessna/ARC Division
Warren Fucigna	Litchstreet Co.
Dr. Thomas L. Gabriele	Bendix
Arthur W. Galusha	Teledyne Avionics
Kenneth Geisinger	FAA
Mantoux Gilles	MITRE Corp.
Fred Gilmore	FAA
Rod Gilstrap	United Airlines

George Gobberdiel	Ozark Air Lines
Manuel Gonzles	FAA
L. V. Gormont	FAA
Claude Gouillan	UTA French Airline
J. M. Graham	McDonnel Douglas
William T. Hardaker	Air Transport Assoc.
Ralph K. Halvorsen	MIT/Lincoln Laboratory
Terry Hannah	FAA
William Harman	MIT/Lincoln Laboratory
Ron Hanna	American Airlines
E. D. Hart	Bendix
Bill Herndon	Pan American Airlines
David Herschander	Analytic Services
William Horn	NBAA
Don Jenkins	FAA
Hugh H. Jones	IITRI/ECAC
Terry Keech	IITRE/ECAC
Philip J. Klass	Aviation Week
Andrew Koppenhaver	IITRI/ECAC
Thomas J. Kreamer	Air Line Pilots Association
Alex Kuprijahow	H.N.T.B.
Lloyd C. LaGrange	National Trans. Safety Board
Raymond R. Lafrey	MIT/Lincoln Laboratory
Dan Leonard	Aviation Convention News
Robert Leutwyler	U.S. Army
Ginger Levin	FAA
Gary L. Link	Boeing Co.
Louie Liste	ECAC
George Litchstreet	Litchstreet Co.
David J. Lubkowski	MITRE Corp.
Ernie Lucier	FAA
A. C. Mackellar	British Embassy
Jim McClurg	Sperry Flight Systems
A. D. McComas	Bendix
Alvin L. McFarland	MITRE Corp.
Ellis McMillan	Frontier Airlines
Charles W. McWilliams	Wilcox Electric
Clyde A. Miller	FAA
R. J. Miller	Sperry
Robert L. Miller	FAA (Atlanta, GA)
Bill Niedringhaus	MITRE Corp.
Kermit D. Oakley	Piedmont Airlines
Vincent A. Orlando	MIT/Lincoln Laboratory
T. G. Paine	Transport Canada
Gary Patrick	IITRI/ECAC
Daniel Pohoryles	MITRE Corp.
Printemps	D.G.A.C.
G. F. Quinby	Aircraft Owners & Pilots
Assoc.	
Jacques Raia	Pan American Airlines
James W. Rogers	FAA
R. B. Rogers	FAA
William M. Russell	Air Transport Association
Sam Saint	Safe Flight Inst. Corp.
Paul H. Sallade	Honeywell

C. W. Schild	Consultant
Schroer	Tu Brauuschweig
George K. Schwind	United Airlines
Tom R. Shafer	Rockwell International
Mike Shinomiya	Panasonic
Allen I. Sinsky	Bendix
Harriet J. Smith	U. S. House of Representatives
R. Sobocinski	Dalmo Victor
Capt. Wm. R. Sonnemann	Trans World Airlines
Carroll A. Spencer	Air Lines Pilots Association
Ned A. Spencer	MITRE Corp.
Richard G. Stutz	Sikorsky Aircraft
Ron Swanda	GAMA
Lawrence Taubenkibel	FAA
Joe Tier	Bendix
Bill Uhl	Republic Airlines
Lt. Col. Wilfred G. Volkstadt	U.S. Air Force
Carol Wales	MITRE Corp.
J. Lane Ware	Thomson-CSF, Inc.
Robert Warner	Aircraft Owners & Pilots
Association	
Jerry D. Welch	MIT/Lincoln Laboratory
Frank C. White	Dalmo Victor
Thomas Williamson	FAA
Alex B. Winick	Consultant
Fred Womack	Piedmont Airlines
Lillian Zarrelli	MITRE Corp.

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